Nature's Miracles

Familiar Talks on Science

BY

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Energy and Vibration

Energy, Sound, Heat, Light, Explosives.

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TO THE READER.

This volume deals with the primal elements—not only of life but of material existence itself. Without Heat and Light we cannot conceive of the physical universe; and Sound becomes a modification of these, without which animated creation would soon destroy itself, and even while it lived would fail to develop, lacking the means of communication.

Yet Heat and Light are but special modes of Motion: and Motion is inconceivable without Force and continuing Energy. Therefore we begin our thinking about all these things with a consideration of ENERGY. And it is not altogether an easy subject to understand. The reader will perhaps find it a little "dry" because it deals with matter that requires some thinking on his part. Even the illustrations of the principles involved are of facts not familiar to every one, although they include some curiously interesting experiments.

But "Something for Nothing" is not the rule of life. "Easy come, easy go" is applicable to knowledge as well as to money. We

do inherit large fortunes of wisdom from the times gone before us, but even these we have to work for, if we would get the good of them and make them useful to us.

And this brief word of preface aims only to urge the intelligent reader who really desires to know about the common "Miracles" of our every-day life, to regard the slight "digging" necessary in the earlier chapters as preparing for greater enjoyment of those that follow. It will well repay his industry.

NATURE'S MIRACLES.

ENERGY.

CHAPTER I.

ENERGY A CONSTANT QUANTITY.

To the ordinary mind Energy and Force represent the same thing. And it has not been many years, comparatively, since even scientific men used the words synonymously. Modern chemistry and modern physics make a distinction, and define the two words differently.

"Force" is defined as the cause of motion, or the generator of momentum, while "Energy" is expressed in the motion itself, in its power to do work. Force refers to the causes, while energy refers to work or the capacity to do work. The distinction is one that is difficult to make plain. Strictly defined, Force is any agency that can cause a motion, arrest a motion, or change the direc-

tion of a motion, while Energy is motion or the capacity to become motion, and this carries with it the idea of work. Force will be more fully defined farther on.

There are two kinds of energy—kinetic or moving energy, and potential or energy of position. In discussing this subject it is our wish to get clearly into the mind of the reader the great physical law known as the "conservation of energy"; how it is related to animal and vegetable existence and especially how it may be related, if at all, to that higher order of existence that seems to be so intimately connected with the mind and soul.

The phrase "conservation of energy" does not cover the whole subject that it is intended to cover. It involves the correlation of energy, or, as it has been called in earlier times, the correlation of forces, as well as the transmutation of energy, by which is meant a change from one form to another. For instance, heat as an energy may be converted into another form called electricity, and this in turn may be reconverted into heat. This process is called transmutation. The energy, as such, representing a definite amount of work, remains the same in both cases. Heat, light, magnetism, electricity, are all different modes or forms of energy working through motion; the fact that they are interchangeable is their "correlation"; the fact that the amount of

energy remains the same through all changes is its "conservation." Energy is a constant quantity.

Faraday once said to Tyndall, who was then a pupil of his in the Royal Institution—when Tyndall was about to show him some experiment—"Tell me first what I am to look for, so that I may more readily see it as the experiment progresses." These are not his exact words, but the substance. Writers often make the mistake of not stating clearly in the outset the point or points that they are endeavoring to prove. The reader must wade through the whole argument, which is often very wordy and obscure, to finally find the whole subject summed up on the last page. In a work of fiction this procedure is all right, for the chief interest of such a work, aside from the philosophy that may be contained in it, lies in the fact that the climax of the story is obscured or hidden until the last moment. There is a sort of excitement in such a pursuit which keeps up the interest of the reader, and the interest is largely in proportion to the ability of the writer to more or less effectually obscure the outcome of the story till the last page of the book is reached. When, however, we are in search of scientific truth the opposite is true. One wants to know in the very beginning what it is that the writer intends to prove. The interest of the reader is then kept

up in noting, as he proceeds, how nearly and how clearly the writer sets forth the facts of his argument and proves his points as he goes along.

The point that we wish to emphasize, then, is this: We are not to confine the discussion to our little planet, as it is related to Energy. Our world may freeze up, some time, and the sun may lose his heat; but the Energy of the universe will remain the same in some form. Like Matter, physical Energy is indestructible, and the sum of all the forms of Energy in the universe remains a constant quantity.

Matter is found in many forms and combinations, producing results of almost infinite variety. There is but one energy in the physical universe, which appears in many guises; and it may be that there is but one ultimate form of matter. This latter, however, is, up to the present time, a speculation that is unproved. Chemistry asserts that there are between sixty and seventy elemental substances in nature. By "elemental substances" we mean a substance that cannot be divided. Gold, for instance, cannot be changed or divided into two or more substances, but, whatever the process of analysis we may apply to it, the molecule or atom of gold remains gold. And this is true of every other so-called "elemental substance."

While they cannot be further separated they can be combined with each other, and it is this combination in various relations of the atoms to each other of these sixty or seventy elementary substances in nature that form all of the numerous compound substances: and their name is legion. These elemental atoms may be driven from one combination to another in thousands and thousands of ways, but no one of them is ever lost. As atoms they may be hidden from our view when combined with other atoms to form molecules of new substances, but the chemist by well-known processes can bring them out from their hiding-places and force them back to their elemental homes. Here we must stop.

Matter, like energy, then, is indestructible, and the two are so related to each other in some mysterious bond that we cannot think of the one dissociated from the other. We speak of "dead matter," although in actual fact all matter is associated with an ever-present force that keeps its ultimate particles in a continuous state of activity. By dead matter we mean that which is inanimate and not incorporated in a living organism. By long study and contemplation one may be able to get a mental picture of the difference between what we call animate and inanimate matter, but no language has ever yet been invented that is able to transfer a correct pho-

tograph of the mental picture existing in the brain of one man to that of another.

Philosophers often attempt to get around this difficulty by coining new words, which are utterly meaningless to the ordinary mind unless they at the same time furnish us with a glossary or a set of definitions. But in these cases the definitions are often more difficult to understand than the original words. They are like the minister who when he was teaching a Sabbath-school class told the children that they must be "born again." He said to them: "Children, you may not understand what this means. I will explain it. It means regeneration." In this case were these little children any wiser after the new birth had been defined than before?

Faraday says: "The whole stock of energy or working power in the world consists of attractions, repulsions, and motions. If the attractions and repulsions are so circumstanced as to be able to produce motion, they are sources of working power, but not otherwise." Right here let us illustrate the difference between force and energy.

When a stone is lying upon the surface of the earth it is held down by the force of gravity. It possesses no energy actual or potential, that is to say, it is neither doing work nor has it the power to do work unless the conditions are changed. We cannot say,

however, that force has been destroyed, because it is the attraction of gravitation that holds the stone against the earth's surface. If now we elevate the stone to some position above the earth we have given it a potential energy; that is to say, we have put it into a position where the force of gravitation can cause the stone to do work if it is released and allowed to fall to the earth. That force has become a potential energy. The attraction is just as great practically after the stone has been elevated as before; but it is in the position now of a bent bow, and if released it can do work. The motion of a cannon-ball when fired from a gun, the motion of a falling body from an elevated position, the turning of a wheel and the vibratory movement of the atom as sensible heat, are all instances of actual or moving energy. The bent bow held in that position, the elevated weight, static electricity, and permanent magnetism are instances of energy of position, or potential energy.

It is a law of physics that action and reaction are equal. If we should take a gun-barrel open at both ends and place a charge of powder in the center of the barrel and a bullet on each side of the charge, and then fire the powder, the gun would shoot in both directions with equal power. If, however, we plug up one end of the barrel rigidly and mount it in a stock, in the ordinary way, and load

and fire it, the bullet is propelled with a certain energy that is determined by the weight of the ball and the velocity of its movement. In this case, however, the law holds good that action and reaction are equal. Every sportsman knows that when he fires his gun there is a recoil against his shoulder. Although in this case the action of the ball and the reaction or recoil of the gun are equal, it makes a great difference whether one places the muzzle or the butt of the gun against his shoulder.

The mechanical energy of recoil, however, is very slight as compared with that of the bullet when it leaves the muzzle of the gun. The former is mostly absorbed in overcoming the inertia of the gun, which is so much heavier than the bullet, and it passes directly into heat. If a gun could be made strong enough and still have no more weight than the bullet it fires, it would be a dangerous gun to handle; for in this case the energy of the recoil would be equal to that of the bullet itself, and while the bullet might kill the game, the sportsman would be in an equally dangerous position.

In constructing a cannon provision must always be made for its recoil when fired. A cannon that fires a very heavy shot must itself be heavy, for two reasons: first, in order that it may be strong enough to resist the charge of powder, and, secondly, that it may be heavy

enough to absorb the reaction, so that the recoil will not be too great.

If we should plant a cannon in a perpendicular position, with the breech resting firmly upon the earth, and fire it, the earth itself would recoil, and the law of action and reaction would hold in this instance as truly as in the first one cited, where two balls were fired from the same gun-barrel. The recoil of the earth, however, would be so infinitesimally small, because of the great weight compared with that of the cannon-ball, that it can be practically ignored. The energy of recoil is really almost entirely represented by heat. Theoretically, however, we must admit that the earth does recoil. The converse of this is true when a cannon-ball has reached its most elevated position. There is a moment when all of its energy of motion has been converted into that of position (except that which has passed into heat by the friction against the atmosphere), and then the ball and the earth attract each other by the force of gravitation and they move toward each other. The weight of the ball is so infinitesimal as compared with that of the earth that the movement of the latter would be an almost immeasurable quantity. However, the law holds good both in the flight of the ball upward and in descent. If this same cannon-ball could be caught by some power and held

in its extreme elevation, the measure of its positional energy would be the same as its energy of motion. In other words, the ability to do work if it were released in its fall would be as great as that which it possessed in its upward flight. If it could pierce a 16-inch armor-plate 100 feet above the muzzle of the gun, it would have the same ability to pierce the same plate at the same elevation in its descent.

We do not mean to say that it could pierce the plate in both the ascent and descent, but that it could pierce once, and it would make no difference whether this was done in its upward or downward flight. This statement does not take into account the resistance offered by the air, but simply the push of the force of the explosion and the pull of the force of gravity. The moving energy of the ball might be totally spent in the passing through the plate on its upward flight and fall immediately to the ground from that position, or it might be fired to its full height and strike the armor-plate on its descent.

And now the question may properly be asked, What has become of the energy that the cannon-ball possessed before it struck the armor-plate on its upward flight? As we have seen, the velocity of the ball was totally arrested when it struck the plate at an elevation of 100 feet, and from this point it falls back

to the ground. If the plate had not been placed in the track of the cannon-ball, its flight upward may have been a mile, or several miles, but all of this wonderful power has been spent in simply piercing the plate; where has its energy gone, if the law of conservation is true, as we have stated? All that is visible to the eye is a hole in the armor-plate, and the ball—which has only been able to simply pass through it at an elevation of 100 feet and then fall to the ground, where it lies an inert mass. What has become of its energy? We will try to answer this question.

The firing of the shot was the result of a sudden release of potential energy that was stored in the substances of which the powder was composed. An application of heat to the powder set in action the chemical process called combustion, which suddenly caused a large portion of the powder to assume the gaseous form, when it immediately tends to occupy a space many hundreds of times greater than the powder did. This sudden expansion drives the shot from the gun with an energy that is measurable, and, as we have seen in the case supposed, sufficient to pierce a heavy armor-plate. This tremendous energy that a moment ago exhibited itself in the form of visible motion has not been destroyed, as appearances would indicate. All of it has

been converted into molecular energy in the form of heat. Heat is defined as a movement of the ultimate atoms of matter, and is therefore energy of motion, and in this respect is like the energy of the moving cannon-ball. We call heat molecular energy and motion of a mass mechanical or visible energy, both belonging, however, to the same general class—energy of motion. One is a movement of the atoms of matter within a mass; and the other is a movement of the mass itself. While the cannon-ball was moving, it was the embodiment of both forms of energy, molecular and mechanical. After it had been arrested by piercing the plate of metal, that which was before mechanical has been added to the molecular energy of both the cannon-ball and the plate, so that the molecular energy of both have been intensified; for, if now we examine the cannon-ball and the plate, we shall find that both have been intensely heated. The ball may have been heated even to the point of redness. If the mechanical energy had been great enough and the plate thick enough the cannon-ball might have been heated to the melting point. The energy that was before mechanical has become molecular in the form of heat; none of it has been lost. Some of it resides in the gun-barrel caused by friction of the ball, some of it is in the air, caused by the same kind of friction, but most of it is

found in the increase of temperature in the ball itself and the plate that arrested it. All of this gathered up and placed back into energy of position would, if again released, fire the shot with the same energy as before.

The mechanical energy of a shot does not represent all of the energy created by the burning of the powder. A part of it has escaped with the heated gases that rushed from the muzzle of the gun, and a part is stored in the ball as heat in overcoming its inertia.

This brings us to the discussion of what is called the "mechanical equivalent" of heat. It has been proven by experiment that the quantity of heat necessary to raise one pound of water to the temperature of 1 degree Fahrenheit is equal to that generated by a pound weight falling from a height of 772 feet against the surface of the earth. Conversely, an amount of heat necessary to raise a pound of water 1 degree Fahrenheit in temperature would, if all is converted into mechanical energy, be sufficient to raise a pound weight 772 feet above the earth. The unit of measurement called the "foot-pound" has been adopted as a means of determining the amount of energy expended in doing a given piece of work. The foot-pound is a unit of energy as expressed in work, and is that amount of energy which is necessary to raise one pound weight one foot high against the force of

gravity. It follows from this that the amount of heat necessary to raise a pound of water 1 degree Fahrenheit is equal to 772 foot-pounds, which constitutes the mechanical equivalent of heat. We thus have a means of measuring energy, whether mechanical or molecular.

This brings us to a point where it is well to define a little more clearly what is meant by work. Work is divided into different classes—for instance, mechanical work is performed when sensible masses are displaced, as opposed to molecular work, in which case there is a displacement of invisible molecules. When a gun is fired, work is done by the energy of the ball in overcoming the resistance of the air and gravity. A certain amount of the heat generated by the ignition of the powder has been absorbed in propelling the ball forward. In other words, molecular has passed for the time being into mechanical energy. This mechanical energy begins to be transmuted or changed into molecular energy the moment the bullet leaves the muzzle of the gun in its attempt to overcome the opposing resistance of air and gravity; for the bullet becomes heated and the air becomes heated until the bullet finally comes to a state of rest. The heat that the bullet has generated in the air and in itself as well as in the earth when it struck, is an exact measure of that which was absorbed from the heat created by

the burning of the powder. So that for a brief moment the energy that was freed by the ignition of the powder existed in two forms of moving energy: one we call mechanical, as manifested in the movement of the bullet through the air; and the other molecular, existing in the form of heat. The sum of the two forms is equal to that which exists as molecular energy or heat, after the mechanical energy of the bullet has been spent. When a body is heated there is a certain amount of internal work done by increasing the rapidity and amplitude of the movement of the atoms.

Work may be resistant work, or motor work. When we undo work that has been already performed it is called negative, or resistant work. It is laid down as a principle that the total work performed upon a particle is equivalent to the kinetic or moving energy it gains; and the total work undone is equivalent to the kinetic energy it loses. If in performing a certain work it is attended by more or less friction, the same amount of work is performed in either case.

When work is performed by a piece of machinery that is driven by a fixed standard of power, the amount of effective work that will be performed will depend upon the friction that has to be overcome in driving the machinery itself. If the friction is great, the

effective work will be lessened. The real work performed, however, will be the same whether the friction be much or little, as it requires an expenditure of energy to overcome friction. And the measure of the energy expended is found in the heat which the friction produces.

CHAPTER II.

ENERGY OF MOTION AND OF POSITION.

Energy performs work when it falls from a higher to a lower level. Whenever energy is stored it is in a position to do work if released. As we have before said, stored energy is energy of position, or potential energy. It may exist in a great many ways. The power that has stored it is equal to that which it will give up when it is released and falls back to the level from which it was originally taken. If a cannon ball is fired perpendicularly in the air, its moving energy begins to be changed from energy of motion to that of position the moment it leaves the muzzle of the gun. Its velocity is being continually reduced by the constant pull of gravity and the resistance offered by the air. These two resistances cause the ball to move slower and slower as it mounts higher and higher until it reaches the turning point, when for a moment there is no motion of the ball, and all of the energy of motion has passed into that of position. At every point in its upward flight the sum of the two forms of energy

remained a constant quantity; that is to say, if at any point in its flight we measure the energy of position it has acquired we shall find that the sum of the two is equal to the energy of motion when the ball was moving at its highest velocity. When it has reached its extreme limit, the ball still possesses the same power to do work that it had the moment it left the muzzle of the gun. In its downward flight, at the moment it begins to descend, it also begins to give up its energy of position and to take on to the same degree energy of motion.

Energy of motion increases while energy of position decreases in its downward movement until it has reached a point on a level with the muzzle of the gun, when it has given up all of its energy of position and has been changed to that of motion. Suppose it strikes a solid substance in its fall, it will do this with the same energy that the ball had when it issued from the muzzle of the gun. Here another transmutation takes place, for the sudden arrest of the movement of the ball has converted what was before mechanical energy into molecular energy—in the form of heat. It is still moving energy, but no longer a movement of the mass, which is called mechanical or visible, but it is represented by an increased movement of the ultimate particles of the mass, which we call molecular energy.

In the whole process there has been no change in the amount of energy; it has simply gone through a series of transmutations. First it was energy of position held in the powder by the force of chemical affinity. When this was released by igniting the powder, a portion of its energy was transferred to the ball, which robbed the gases of a portion of the heat and passed from molecular into mechanical energy, which in its flight upward has been gradually converted into energy of position; in its fall downward it is gradually reconverted into mechanical energy, and finally, when it strikes the earth, there is another transmutation into that of molecular, and a new production of heat. (Friction against air is not here considered.)

Another instance of energy of position may be found in a body of water having a level higher than that of the ocean's surface. If this body of water is released it will flow down to the lower level, and during its progress it is able to do work, such as grinding grain, sawing wood, or driving the machinery of a factory. When it has reached its lowest level it no longer possesses the power to do work. In order to restore to it the same power that it had at the higher level we should have to expend the same amount of energy in pumping it back that it gave up when it ran down. As a matter of fact we should have to expend a

great deal more, because of the great amount of energy that would be lost in the form of friction in the machinery employed for the purpose. In discussing this question, however, we are assuming that all of the energy can be employed in the actual work of raising the water.

Another form of energy of position is seen in the bending of a bow. The bending of a bow has required a certain amount of energy, which, when released, is imparted to the arrow, which now represents as moving energy what the bent bow did as energy of position. If there were no attraction of gravitation, and if the arrow were flying through a vacuum instead of through the air, the arrow would move on forever with the velocity it had when it left the bow. In and of itself it has no ability to change its velocity or direction. The energy imparted to it would continue with it as moving energy. But the moment it is resisted, as it is by gravitation and by passing through a resisting medium, such as the air, the energy of mechanical motion is gradually changed into that of molecular motion, until the whole of the former has passed into the latter, when the arrow comes to rest; but the measure of energy remains the same.

Another instance of energy of position is found in the spherules of moisture that are drawn from the surface of a body of water

by the action of the sun's rays and carried to the upper regions of the atmosphere. Here they may float around for days, weeks, or months, each one carrying its little load of energy, which is given up at the moment the conditions are right for condensation into raindrops. At the moment of condensation the energy that was stored in the moisture spherule by the power of the sun's rays is given up in the form of heat, or electricity, or both. It may appear first as electricity until the cloud is charged to the point of disruption, when the whole is converted into heat through the electric discharge. All of the phenomena of a thunderstorm, hailstorm, or tornado, with their terrific manifestations in the form of thunder, lightning, wind, and rain, are simply the result of a sudden releasing of the stored energy in the myriads of moisture spherules that were placed there by the power of the sun, when they were silently and invisibly wrested from the surface of the water, or from condensed moisture globules floating in the air.

If we should measure the energy that is released during a thunderstorm by the condensation of moisture spherules, and follow it through the various manifestations of thunder, lightning, wind, and rain, together with the energy set free in the form of heat, the whole of the energy expended in these

various manifestations would be found equal to that expended by the sunbeam in disengaging and carrying the moisture spherules to the upper regions that were condensed into raindrops during the progress of the storm. The sun has marshaled its forces silently, so that no one is aware of the vast energy that is being expended until the storm bursts upon us.

Another form of stored energy is manifested in the winding up of a weight or spring; the amount of power that has been expended in winding up the weight may be utilized in its descent when released to drive machinery, as of a clock, and perform various kinds of work. The function of a machine, and its only function, is to distribute energy that has been stored, in a manner that will be most convenient for our purposes.

Energy cannot be created by the introduction of any form of machinery. By no possible means can more work be gotten out of a machine than it has required to create the energy of position which will drive it. Not only is it true that we cannot get more power out of a machine than was put into it, but in practice it is true that we cannot get so much. If all kinds of friction could be done away with, we could take out the same amount in effective work that was put into the winding of the weight, but no more. If

the weight is made to turn a system of wheels, each wheel will have its bearings that will cause more or less friction. The meshing of the cogs between one wheel and another will be an additional source of friction, and to this must be added the resistance offered by the air to the motion of the wheels. We have already seen that the arrest of motion is followed by a corresponding production of heat. In comparing the effective work done, then, in winding up the weight that drives the machine with that which it will perform in running down, we must deduct all the energy that passes into heat caused by the friction of the bearings, the cogs, and the resistance of the air. This, added to the effective work performed, will be equal to that expended in raising the weight. It will thus be seen that by no possible means can power be gained by machinery, but machinery enables us to utilize power in many convenient and highly advantageous ways that would be impossible without its use.

It was an old notion that power could be gained by machinery, and many men have spent years of time as well as fortunes in pursuing this will-o'-the-wisp, which, if true, would enable us to construct a machine that would propel itself. From their standpoint an animal or a man seemed to be a realization of a perpetual motion. They did not

take into account the fact that the food which an animal eats and the air that it breathes sustains the relation, in a sense, to animal locomotion that coal burned under a boiler does to the propulsion of a steam engine. In both cases there is oxidation caused by the union of oxygen with the carbon, the result of which is the production of heat. Many ingenious automatons were constructed that would simulate the movements of men and animals in the performance of certain kinds of work; and their ingenious constructors had in view the solution of a greater problem than that of the construction of a mere mechanical toy.

History speaks of a mechanical duck that was the wonder of the last century, that fed and digested its own food. The same inventor is said to have constructed a flute-player that would move its fingers in the proper manner to produce a certain melody. Later on another ingenious mechanician constructed a writing boy who would go through all the motions of writing accompanied by the proper movement of fingers, arms, and eyes, and so perfectly was this piece of mechanism adapted to the purpose for which it was intended that when the "boy" and his father (who invented and constructed him) were traveling and giving exhibitions in Spain they were both arrested for being in league

with the powers of darkness and subjected to the tortures of the Spanish inquisition.

The officials tortured the father, but not the offspring of his genius. For the writing boy was merely a highly organized machine, containing nothing more wonderful than the ordinary cuckoo-clock. The materialism of the age in which these geniuses and philosophers lived led them to suppose that the problem of life could be solved by mechanics and chemistry. Whether they had in mind the construction of a mechanical man that could eventually be endowed with moral qualities we do not know. We do know, however, that no greater blessing could come to modern civilization than the construction of a mechanical servant girl that would do just what you wanted her to do without "talking back." We could afford to dispense with moral and intellectual qualities if all the other disagreeable qualities could be dispensed with as well.

The law of the conservation of energy is teaching men that something cannot be made from nothing. And this is what every man is trying to do who is deluding himself with the idea that a perpetual motion is possible.

CHAPTER III.

THE FORCES OF NATURE.

Having now, in a general way, given some idea of what is meant by Energy, in its two forms of motion and position, let us stop a moment and consider what are called the forces of nature. Force has been defined as the cause of motion, and Energy the motion itself, or the ability to pass into motion.

A weight that is elevated from the surface of the earth and suspended possesses something that it did not possess before it was elevated. This something is its ability to fall when released, and this ability we call Potential Energy. While it is falling it possesses Moving Energy. So far as the weight is related to force it is acted upon equally whether it lies upon the ground or is suspended in the air. This force we call Gravitation, and, as compared with some of the other forces, it may be called a very weak force acting through very long distances.

It is the force of gravity that causes the tides, occasioned by the mutual pull between the earth and the moon. The attraction of

gravitation between the sun and the earth is also felt and made sensible in the tidal phenomena. So true is this that there is a very great difference in the height to which the tide rises when both sun and moon are pulling upon the earth in the same line, as opposed to that which takes place when they are in opposition to each other. In the case of the sun the attraction of gravitation is acting through a distance of over 90,000,000 of miles. The sun's attraction is less than that of the moon, because of the greater distance through which the attraction has to act. If the two were equidistant from the earth, the attraction of the sun would be many, many times greater than that of the moon.

There are other forces in nature that are in a sense like the attraction of gravitation. They differ in the respect that, when the bodies between which the attraction exists are sufficiently close together, it is very powerful; but it is totally lost the moment there is any perceptible separation.

First of these, let us consider the force called Cohesion. This force is the attraction which one molecule has for another, or mass of molecules have for each other, acting, however, through an infinitesimally small space. A pane of glass is held together with great rigidity, but the moment a crack runs through it, although the parts each side of the crack

seem to be in solid contact, the two pieces have lost all attraction for each other. The attraction of cohesion, then, exists between the molecules of matter, and, unlike gravitation, it acts only through an extremely short space.

A moment's reflection would show us how extremely inconvenient it would be if it were otherwise. On the other hand, it would be just as inconvenient if gravitation did not act through very long distances, as we find it does. If, for instance, it were like cohesion, there would be nothing whatever to hold us down to the earth as soon as we had raised our feet from it. What the boys call a "broad jump" would become a very "high jump."

There is another force, called Chemical Affinity, which is very much like cohesion in that it acts through very short distances, but its attraction is not between the molecules of a substance, but between the atoms of which the molecules are made up. The study of the laws that govern this force is one to which the chemist must especially address himself.

For the purposes of our subject we may treat the attraction of cohesion and the attraction of chemical affinity the same as we do the attraction of gravitation. It requires energy just as truly to overcome these attractions as it does to overcome the attraction that

gravitation has for a stone lying upon the surface of the earth. It requires energy to raise the stone from the surface of the earth to some fixed elevated position. It requires energy, also, to overcome the attraction of cohesion by separating molecule from molecule; and it just as truly requires energy to overcome the attraction of chemical affinity and thereby rend atom from atom as they are related to each other in a molecule of any substance. If we apply heat to water, a portion of that heat is made sensible in the water by an increased action of its ultimate particles, the intensity of which may be measured by a thermometer, while another portion of the heat is expended in a rearrangement of the molecules when it passes into a state of vapor.

Another and a vastly greater amount of heat is again absorbed in the internal work of breaking up the water molecule and converting it into its constituent gases, oxygen and hydrogen. We now have Stored Energy (or energy of position) existing in these gases by the act of chemical separation, just as truly as we have Potential Energy stored in a weight that has been elevated from the surface of the earth, which we may call mechanical separation.

We have spoken of the analogy or likeness existing between the atoms of oxygen and

hydrogen and that of a weight elevated from the earth's surface, in the respect that both possess energy of position. Let us trace for a moment the processes used in attaining the position in both cases. When we apply heat to a boiler, a part of this heat is converted, through the medium of a steam-engine, into mechanical rotary motion. By the energy of this motion we are enabled, through the medium of a rope and a pulley, to wind up a weight to an elevated position. A part of the heat that has been generated by the burning of the fuel appears simply as sensible heat, while another passes into mechanical energy, which is used in winding up the weight.

To produce chemical separation we also may apply heat, a part of which will appear as sensible heat, measurable by means of a thermometer, and a part will be absorbed in the work of separating atom from atom. In the case of the wound-up weight the energy set free by the burning of the fuel exists partly as sensible heat that has radiated off into space and partly as stored energy in the wound-up weight. If the weight is allowed to fall it becomes molecular or heat energy when it strikes the earth; and the sum of the energy —to wit, the heat developed by the fall of the weight and that which radiated into space during the process of winding up the weight

—is exactly equal to the amount that was originally developed by the burning of the coal. In like manner the heat that was employed to separate the molecules of water into its constituent gases has been given back as sensible heat when the atoms clash together again by the force of chemical affinity to form water. The measure of the heat absorbed in forcing the atoms apart is precisely the measure of that which is given up when they reunite to form water.

The green leaves of the forest have the power to gather up from the air the carbon dioxide and the vapor of moisture. That wonderful laboratory of nature, the chlorophyl of the green leaf, calls to its aid the power of the sunbeam and rends the molecules of water and carbon dioxide, atom from atom, stores the carbon and hydrogen in the woody fiber, and throws back into the air the pure oxygen. It has required energy to produce this chemical separation which is stored in the woody fiber, and when the wood is burned as fuel it gives back in the form of heat the measure of the energy expended by the sunbeam in the growth of the wood. The energy that is stored in wood and coal is therefore energy of position.

Another form of energy of position is seen in electrical separation. If we rub two substances together, such as a silk handkerchief

and a glass rod, the rod and the handkerchief are said to be electrified oppositely. The glass will have a static charge of positive electricity and the silk will have an equal static charge of negative electricity. Neither of these substances is a conductor of electricity, and therefore the charge cannot be immediately dissipated. The two kinds of electricity are in a state of tension with reference to each other, just as a bow and its string are when the bow is bent. If released they will fly together and their attractions will be satisfied. When we rub the glass rod with the silk handkerchief, energy is expended in doing it. A part of this energy appears as electricity, on the rod and on the handkerchief, and a part is represented by heat.

In order to produce this electrical effect the two substances that are rubbed together must not only be nonconductors, but they must be unlike in molecular structure. They must be heterogeneous and not homogeneous. If we were to cover the glass rod with the silk, the rubbing of silk on silk would produce no sensible electrical effect. The mechanical energy put forth in the rubbing would all, in this case, be directly converted into heat, while in the former case a part of the energy first appeared as electricity. If we construct a galvanic battery, the two metals used must not be alike, and the greater the difference there is

in their molecular structures the more favorable are the conditions for producing electricity.

If instead of using copper and zinc for the two elements we should simply use two pieces of copper or two pieces of zinc, we should get no electrical effect. This statement supposes of course that the metals are perfectly homogeneous.

If we set up an ordinary galvanic battery and connect wires to the two poles of the battery, these two poles will be in a state of strain with reference to each other,—the strain existing in the ether.* If we bring the two wires together, the energy in the form of electricity begins to fall from the metal possessing the higher "potential" (possible electrical energy) in proportion as it is released by the action of the acids.

In the case of zinc and copper, or zinc and carbon, the fall is from the zinc toward the carbon or copper. All metals possess a certain potential, which in this case we will call energy of position. When they are dissolved by the action of acids this energy will be given out, and if opportunity is afforded there will

* The ether is a substance supposed to exist throughout the universe—between atoms as well as between stars—and to be the medium through which radiant heat, light, and ether-waves created electrically are transmitted, as sound is transmitted through the air. It will be more fully treated in future chapters.

be a flow from the higher to the lower potential.

Let us illustrate. Suppose we have two reservoirs of water, both of them occupying the same level and both of them above sea-level. Both of them would be in a state of potential, and possess energy of position with reference to the sea, because the water can be drawn off, when it will fall down to the sea-level, and in its onward course possess the ability to do work. But, considered with reference to each other, the two reservoirs are equi-potential. If we connect them together no water will flow from one to the other. They are in the condition that two pieces of zinc would be put in the same battery cell. They are equi-potential, and therefore there is no fall from one to the other. If we pour acid into the cell it will attack both pieces of zinc, but the energy given up will be in the form of heat. If we take out one of the pieces and substitute a piece of copper or carbon, and connect the two together, we have a flow of electricity from the zinc to the copper.

CHAPTER IV.

TRANSMUTATION OF ENERGY.

It will be seen from the foregoing chapters that the energy of the universe exists in various guises, which we call the "forces of nature."

We have visible energy of motion, as seen in the flow of water, the movement of the heavenly bodies and the firing of a shot. We have visible energy of position, as seen in a reservoir of water elevated above sea-level, or in a weight that has been carried to some position above the surface of the earth. We have energy of position in molecular separation and in atomic or chemical separation. Also there is moving energy in the form of heat motion, the motion of an electric current and that of radiant energy. These are some of the forms of energy existing, and so far as the universe is concerned the sum of them remains a constant quantity. They are not really different energies, but the same energy appearing under different guises.

It will be seen that all work performed must come from energy of position. The tendency

is to fall from a higher to a lower level. Water will not turn the mill unless it is first elevated from the level of the common reservoir, the ocean.

This, however, is going on through the process of evaporation caused by the power of the sun's rays. There is a constant elevation of water in the form of vapor and a constant precipitation upon the higher levels of the earth where it runs back again to the common reservoir, the ocean.

In like manner heat, in doing work, falls from a higher to a lower level. We build a fire under a boiler, when a part of the heat communicated to it does a certain amount of work in forcing the water into vapor. This is converted into mechanical work in passing through the engine, when it escapes into the air and is radiated into space. Not all of the heat, however, that is forced into the engine from the boiler issues from the escape-pipe, for a part of it is converted into mechanical work in turning the wheels of the factory and performing the various kinds of work carried on therein, when finally this portion is given up as heat caused by the friction of the bearings, the friction of the wheels against the air in which they run, the friction of the tools used in planing, or turning, or boring, as the case may be.

If we take the temperature of the steam

as it escapes and compare it with the steam before it enters the engine, we shall find that the temperature of the former is very much lower than that of the latter. A part of the heat that comes from the boiler is radiated by the pipes carrying the steam and by the engine through which it passes, a part of it escapes with the exhaust steam, while the balance is first converted into mechanical visible energy only to be converted into molecular or heat energy through the various sources of friction heretofore mentioned. If the heat outside of the boiler were as great as it is inside of the boiler we could get no work out of it any more than we could get work out of two reservoirs of water occupying the same level.

It will thus be seen that all of the operations of nature, whether in the animal, vegetable or mineral kingdom, are dependent upon the fact that somewhere there is stored a great reservoir of energy, capable of carrying on all of the activities not only of this world but of many others like it.

So far as our solar system is concerned, that reservoir is the sun. What would happen if this great source of energy should be suddenly cut off from pouring its life-giving streams upon our earth? A moment's reflection will show us that there is only one answer—universal death. The next question

that naturally arises is, will the sun continue to be an inexhaustible source of energy? Probably not. But the diminution of the sun's heat is so very gradual that we have not been able to measure it within historic times. It is not a question that need to trouble us as individuals; but as each one of us must face the inevitable change that comes at the end of the little point of time allotted to us, so the race must look forward to its ultimate extinction as physical beings through natural causes. The human race has greater and higher problems to solve than those involved in our mere physical existence as animals or machines. But in order that these greater questions may be solved, if they ever are, it is necessary that we begin from the physical side of nature's operations. Our philosophical speculations in regard to that which we do not know must be based upon an array of facts that we are intimately conversant with, if we expect to make any real progress.

It is the business of the scientist to furnish these facts, and leave it for the philosopher to harmonize them with other facts in a higher realm that is just as real.

How can we prove that the law of the conservation of energy is correct, as stated? While it is not so easily proven by direct methods as it would be to prove the conser-

vation of matter, yet there are indirect evidences that carry with them such conviction as to amount to absolute knowledge to the individual who has made it a close study. Sometimes we arrive at the truth by trying to prove a proposition based upon false premises.

For several centuries philosophers and mechanics have attempted to solve the problem of a perpetual motion, but without success. The amount of study and money that has been spent in trying to solve this problem has not been in vain. In settling some questions, it answers the same purpose to prove that a thing cannot be done as that it can. When men once made up their minds that power could not be created by machinery, they at once addressed themselves to solving the question—Why? And out of this effort has grown a knowledge of the great law of the conservation of energy. If energy could not be created, then the question arose, Can it be destroyed? And when this is attempted we find that it cannot be done. The one is just as easy to accomplish as the other—if we are able to destroy energy we ought to be able to create it; but we find that neither one is possible. Perhaps the best way to impress the mind with these facts will be to give a few instances of how energy may be transmuted—changed—

from one form to another without our being able either to increase or diminish it.

Let us take the case of a pendulum that is delicately hung upon a knife-edge. Now let us give it an impulse that will set it to swinging. The first oscillation it makes will be greater than any that follow until it comes to absolute rest. In an ordinary clock the pendulum is kept swinging with a definite amplitude by giving it a fresh impetus at the end of every stroke, which is imparted to it through the medium of an escape-wheel, driven by a weight or spring. Let us, however, consider the pendulum without the escape-wheel. If delicately suspended it will swing a long time upon the single impulse that has been given to it. Now let us follow the transmutations of the energy that was imparted to the pendulum. First it appears as energy of motion, which is greatest when the pendulum swings to its lowest point. When it has passed this point its movement is slower and slower, until it comes to rest at the turning-point, when immediately it swings back, passing the lowest point again and rising on the opposite side; each oscillation becoming shorter and shorter, until it finally comes to rest on a line that is perpendicular to its center of gravity.

A casual onlooker would conclude that the energy imparted to the pendulum was now

entirely lost. But this is not the case. As long as it continued to swing there were two transmutations taking place. When the pendulum was at its lowest point it was moving at the highest rate of speed. From this point to its extreme limit of oscillation it changed from energy of motion to energy of position, till at the turning-point the energy that had originally been imparted to it was all that of position, with one exception.

We have seen that each successive oscillation of the pendulum is shorter than the one succeeding; therefore it is plain that the sum of the energy of motion and of position which change places at each oscillation, becomes less and less, until it is entirely gone, when the pendulum stops swinging. The loss in energy of visible motion and position, which occurs at each oscillation, is now all represented by heat caused by friction against the air, and that of the knife-edge upon which the pendulum swings. So that now we have represented in heat the mechanical equivalent of the energy required to put the pendulum in motion. If we could eliminate the pull of gravity, the friction of the knife-edge, and the air resistance, the pendulum would swing on forever from its initial impulse. The law of inertia would not allow the pendulum to stop swinging in the absence of all resistance whatever.

All visible motion, when arrested, becomes heat. When the blacksmith delivers a blow with his hammer upon a piece of iron resting upon the anvil, he creates heat in the hammer, the iron, and the anvil, as well as in the air as the hammer passes through it; and the amount of heat thus produced, if all could be gathered up and applied in the same manner, would strike the same blow, with the same hammer, with the same force—no more, no less. Two or three dextrous blows upon a rod of iron resting upon an anvil will heat it to redness.

Gunners inside of a monitor turret suffer intensely from heat generated by the concussion of the enemies' cannon-balls when they strike the walls of the turret. The energy of visible motion is suddenly arrested and becomes molecular energy in the form of heat. The moving mass has communicated its motion to the molecules of the metal of the turret, as well as of the cannon-ball itself. If the heat created by the impact of the cannon-ball, together with that created by friction against the air in its flight, and that which escaped with the gases, could all be gathered up and put again into the energy of position as it existed in the grains of powder, it would fire the same shot again, with the same energy—no more, no less.

As we have said: all visible motion, when ar-

rested, becomes heat, even that of running water. If we take two pieces of solid ice and rub them together, they can be heated by the friction until the melting-point is reached. If we should pour water into an ordinary rotary churn and turn the crank, the mechanical energy exerted against the water will be transformed into molecular energy, and the water will be warmed in proportion to the amount of mechanical energy expended.

Let us repeat: the sun is the source of the physical energy that carries on all the operations of our globe and of the solar system, so far as energy is related to matter in all its various physical manifestations. What is behind the sun will be referred to later on. While the body of the sun is undoubtedly in an intensely heated condition, heat is only one manifestation of energy. The interplanetary space, that is not occupied by the air or other sensible form of matter, is not heated by the sun's rays as they pass through this great realm of space. The energy of the sun is transmitted by ether-vibrations, the same as light, and while it is passing through the ether it may be called radiant energy, or ether-waves that are converted into heat when they strike the earth. While ether is undoubtedly a substance, there is no means of measuring it or making it sensible. So refined are the particles (if particles they are), of which it

is made up, that all substances that are chemically combined so as to appeal to our senses, are as open to the ether as a coarse sieve would be to the finest flour. From this fact it will be seen how impossible it is to make the ether, that fills all interstellar and interatomic space, appeal to our senses; for no vessel can be made that will hold or resist it. The ether may be said to be continuous, and to fill all space—which is like eternity, having neither beginning nor ending.

This subject will be fully discussed in our chapters on heat, light, and electricity. Ether-vibrations, purely as such, do not manifest sensible heat, so that the great region between the upper limits of the air and the sun is a vast cold space. These radiant vibrations of the ether become sensible heat only when they impinge upon some form of sensible matter.

Let us now follow energy from the sun through some of its transmutations. We will assume (which in all probability is true) that the sun is a great heated body of matter, such as the earth is composed of, in a molten or gaseous state. The heat is radiating from this body in every direction in the form of radiant energy, which does not become sensible heat until it impinges upon some form of matter. When these radiant or ether-waves enter our atmosphere, sensible heat begins

to be manifested more and more till they strike the surface of the earth, where the radiant energy is entirely arrested and becomes sensible heat, which is a motion of the ultimate particles of matter. All of this energy, however, is not immediately converted into sensible heat. Some of it is stored in the globules of moisture that it disengages from the surface of water. Some of it is stored in doing the work of decomposing carbon dioxide and water, and storing the carbon and hydrogen in the form of woody fiber in vegetable growth. We chop down the tree and with it build a fire under the boiler, when the stored sun-energy now reappears as sensible heat.

Heat, as we have said, is molecular energy, and this is communicated to the boiler and the water within it. (The word "molecular" has a technical meaning here. Heat is strictly atomic motion, and atoms combine in various proportions to form molecules.) The water is converted into steam and the steam passes through the engine, where a portion of it is converted into mechanical energy and lost as heat. The engine revolves the armature of a dynamo and here mechanical is converted into electrical energy. Let us pass the current of electricity, thus generated by mechanical force, through a body of water; here the energy is stored in wresting the atoms of

oxygen and hydrogen from each other and setting free the constituent gases that compose the molecules of water. The energy now is that of position. If we combine these gases with proper apparatus they may be burned like a gas-jet, where the energy is given up again in the form of heat. This heat may be applied to making steam and thus go through the same round again—heat, mechanical energy, electrical energy, chemical energy, heat.

To recapitulate: We started with the heat energy of the sun, which becomes radiant energy in the ether, which in turn was stored in the growing wood and was released as heat when burned under the boiler. A part of this heat is stored in the work of creating steam, which is again released, a part of which passes into mechanical motion or energy, which in turn is converted into electrical energy. From this it is stored in separating the molecules of water into its gases and finally reappears again as heat when the gases are burned, again to make steam, etc. Now it is all represented as heat.

It will be observed in this, that there is a great loss at each transmutation in the form of heat. We do not mean to say that there is a destruction of energy, but all of it is not transmuted into the new state or position. When we build a fire under a boiler not all

of the heat is consumed in the process of creating steam—a large part of it goes up the chimney, serving to create a draft which keeps the fire burning. (This is analogous to a hydraulic ram, which is obliged to waste eight or ten parts of water in order to raise one part to an elevated position. The water that runs away is not lost as water, but the energy produced by its fall is only sufficient to raise a small portion of it to a position much above the level of the water of the reservoir from which it flows—just as a part of the heat must be consumed in creating a draft.) A part is lost also by radiation and conduction through the walls of the furnace and steam-pipes. Only from 5 to 10 per cent. of the energy which was released by the burning of the wood finally becomes mechanical energy through the medium of the steam-engine. The energy exists, however, in some form, and it still remains a constant quantity, but it can be converted into work only when falling from a higher to a lower level.

CHAPTER V.

ENERGY—ITS RELATION TO LIFE.

In the foregoing chapters we have discussed the subject of energy wholly in its relation to inanimate matter. When we pass from the inanimate to the animate a new factor is introduced that bears some sort of relation to physical energy. This new factor we call Life. It is beyond the power of the human intellect to dissociate it from the living organisms, or to solve the mystery in which it is shrouded. All we know is that there are certain facts and phenomena connected with all living organisms, whether vegetable or animal, that we do not find associated with inanimate matter in any of its combinations.

In a certain sense a man is a highly organized machine. To obtain the energy with which to drive a steam-engine we only need to release that which is stored up in wood or coal. The machinery which the engine drives will do the kind of work and only the kind for which it has been designed. But it will not do even this work except under the direction of an intelligent being. The forces of

nature left to themselves would never construct a steam-engine and operate it to perform some special work. Behind these forces is an intelligence that directs them at will to perform a certain kind of work in a certain way.

No man has ever been able, from a knowledge of the laws of physics and chemistry, to so combine matter and energy that it will produce a self-acting machine. If we possess an acorn we can so environ it as that it will produce an oak, but the acorn itself possesses the key to the situation. The chemist can analyze the acorn, and tell us what are its chemical constituents, but he never has been able, and perhaps never will be able, to make an acorn that can be planted in the earth and thereby produce an oak. The life-principle—that mysterious something which is a necessity to all growth, animal or vegetable, eludes the physicist at this point. It says to him: "Thus far shalt thou go."

The physical basis of all life, animal and vegetable, is called Protoplasm. It is a glutinous substance resembling the white of an egg. This protoplasm is the substance out of which are developed the cells and tissues of all living beings, whether vegetable or animal, including man. Chemically considered, it consists of carbon, oxygen, nitrogen, and hydrogen. The molecules are extremely un-

stable and are held in position by this mysterious vital spark that eludes the chemist. Take away this vital energy, and decomposition immediately ensues.

Man is a highly organized machine—but he is more. The energy that he expends in doing various kinds of work is deri ed from the food that he eats. There is combustion going on in the human system, the same as under a steam boiler, but less rapid in its action. It does more, however, than merely produce heat that may be transmuted into mechanical energy. A part of the energy is used in carrying the various elements contained in the food into the tissues to build them up and repair the waste that is constantly going on, and a part is consumed in keeping up the heat of the body.

But it will be perceived that the likeness between a man and the ordinary machine is limited. The machine requires the constant attention of an intelligent being to gather up the fuel that supplies it with energy, and, after the energy is developed, to direct it into the various channels of work for which the machine has been constructed. Man gathers his own food and directs the energy of his own mechanism in whatever direction he wills. He is not only the machine but he is the engineer as well. He cannot, however, live and grow on the same food that the

plant does, which draws its sustenance from inorganic matter—rocks and soils, not yet organized into living tissue.

In the vegetable world there are three elements necessary for the operation of growth, and these three are: First, protoplasm; then, chlorophyl, which is the green substance of the leaf; and, finally, the sunbeam. The protoplasm has received its vital energy from a previous existence. There must be this life germ, which is the basis of vegetable as well as animal life and growth. For instance, let us plant an acorn in the ground and watch its development. In its first stages it is shut out from the light from which in after life it obtains its energy, but the previous life has provided for this germinating period that is carried on in the dark by storing up a mass of organic material, which acts as food for the germ until it has reached above the surface and sent forth leaves. The energy necessary for starting the germ is set free when this mass of material that surrounds the germ of the acorn is decomposed. When the leaves put forth, the work of building up the oak is carried on largely through them. The energy of the sunbeam, in connection with the leaf directed by the vital energy inherited through the living germ that came from another life, is able to decompose carbon dioxide and water, storing the carbon and

hydrogen, while it throws back the oxygen into the air. And thus it is that this vital spark directs the power of the sunbeam to accomplish the ends of its own destiny which is predetermined by heredity.

When we analyze the seeds of different kinds of vegetable growth, chemically, it would be difficult to determine one from the other by any experimental test we may apply to them. However, there resides in each germ of a different species a potency that directs its growth so that the one will build up an oak, another a maple, and still another a cornstalk. All of them may be environed exactly alike, planted in the same soil and warmed by the same sunshine, and yet how different the results—when each has matured after its kind!

We have seen that the food of plants is taken from the mineral kingdom. Man's food, however, is derived from the vegetable or the organic world. He cannot, like the plant, draw his food directly from inorganic substances, but it must have been selected and given an organized structure under the direction of a vitality that has been handed down, through an untold lapse of time, from one life to another. Whence the origin of this vitality, physical science does not tell. Evolution has failed to solve the problem, as the closest investigation has shown that there is no such

thing as spontaneous generation—something out of nothing—but that all life comes from another life. To attempt to produce something that does not inhere in inanimate matter (that is, to derive life from no life) will be as futile as the attempt to produce a machine that will perpetually propel itself without the aid of any power extraneous to its own.

Compared with mineral compounds, organized structures are chemically unstable. The vegetable kingdom is more unstable than the mineral in its structure, while the animal kingdom is still more unstable than that of the vegetable. And those parts of the animal that are susceptible of the most delicate and discriminating work are the most unstable structures of them all. The moment the life-principle is taken away the structure begins to break down.

The highest forms of life are found associated with the most delicate machinery—machinery that responds to the most delicate directive touch, and yet that directive touch is beyond the reach of scientific analysis. A mine may be laid in a harbor and so arranged, with reference to collateral appliances, that the most delicate touch of a child's finger will be sufficient to release enough energy to destroy—in the twinkling of an eye—the largest battle-ship that ever plowed the ocean, and yet that slight touch is just as necessary

as though it required the weight of a ton to produce the effect. By no possible refinement of machinery could we get along without this directive energy, behind which, somewhere, lies an Intelligence that determines the when and the how a thing shall be done. It does not detract from, but rather adds to, the dignity of this *Intelligence* to say that He carries on all these wonderful operations through the medium of Natural Law—Law that is inflexible and that pervades not only the physical kingdom, but the kingdoms of mind and soul as well. For whatever *is*, in fact, is natural.

The lesson to be learned by a study of the laws of energy—so far as it is related to life—is, that energy as it is related to inanimate matter can never account for all the phenomena exhibited in life and growth. Here, at length, we come to the border-land. We look over from the realm of the physical into the realm of the spiritual and intellectual, and there we see a train of facts that are just as real as any fact in the world of material. Vice, virtue, love, hate, mind, intelligence, religion—these are facts that the student of nature can no more ignore than he can the facts of heat, light, or electricity. We are bound to recognize these facts, although we may not be able to explain them. They cannot be explained from a purely physical stand-

point, but before the philosopher can reconcile them with the facts of the natural world he must know and recognize them. There is no correct thinking without a mutual recognition of the facts in both realms, by both the physicist and philosopher.

From the foregoing, three facts are made to stand out in bold relief, namely: Matter, Energy, Intelligence. The two former, as we have seen, are indestructible, and we are forced to the conclusion that the last-named either ante-dated or was co-existent with the former. Moreover, since the first two obey, and the third commands, Matter and Energy must take a subordinate position to Intelligence.

VIBRATION.

CHAPTER VI.

SOUND.

Having now formed some idea of Energy, as the actual exertion of Force at work, we come to a consideration of Vibration, which is the mode of motion used by all the natural forces when in action. Vibration is an oscillation, or shaking to and fro, made by a stationary body (like a pendulum, or a stretched wire) when disturbed from its equilibrium or rest. When this motion is slow—as of a pendulum—it is called oscillation; when rapid—as of a wire or tuning-fork—it is called vibration. The latter term is used also in describing the action of a disturbed fluid—as of water, air, or ether—when it results in a wave-motion, a phenomenon so familiar that it needs no definition. The effects of Sound, Light, and Heat are all produced through vibrations of the medium transmitting the disturbing force. We will begin with the first named.

Sound is one of the important mediums through which the inner man communicates with the outer world. It may be defined as Motion or Vibration, in its objective or outer manifestations, and as Sensation in its effect upon our consciousness through the medium of the organs of hearing.

There are many avenues to the brain that are in touch with the outer world through the medium of the five senses. Through all of these avenues the same general vehicle is used to carry intelligence to the brain of the percipient—to wit, motion.

It is motion of the optic nerve that carries to the brain the sensation of light. It is motion of the gustatory nerve that carries to the brain the sensation of taste. It is motion of the olfactory nerve that carries to the brain the sensation of smell. It is motion of the nerves of feeling that carries the sense of touch; and it is a motion of the auditory nerve that gives us the sensation of sound.

Nothing but sound can be transmitted through the auditory nerve, and nothing but light through the optic nerve. The same is true of the other avenues to the brain; you cannot smell with your tongue or taste with your nose: although the sense of taste and smell are very closely allied; that is, we often taste and smell at the same time, but attribute the sensation all to taste. Put a cinnamon

drop on your tongue and hold your nose and you will taste only sugar. You get the taste of cinnamon only when the nasal passages are open. We really taste and smell at the same time, in some instances, and call it all taste. Each special nerve has its special use. If we have lost one of these highways between the outer world and the inner self, by so much we are dead to physical things.

All the phenomena of sound, outside of the point where we perceive it, are simply motions of some character. The different kinds of sound are infinite, but each sensation of sound that differs from another has its correlative in the air outside of the ear as a peculiar form of motion. For instance, if some one out of sight, but not out of hearing, should sound a note on a violin, you would say that you heard a violin; but if some one should sound a note, of the same pitch, on an organ, you would say that you heard an organ. What is the difference? Simply that the kind or quality of the motion made by the violin differs from that of the organ; hence the difference of the sensation. What this difference is will be fully explained in its proper place.

Let us now go back and follow out the course of a single sound-impulse from its source to the ear, and through it to the brain—the seat of sensation.

Let us fill a soap-bubble with oxygen and hydrogen gases in the proportion of two parts of hydrogen to one of oxygen. If we ignite it the result will be an explosion. When the ignition takes place there is a sudden generation of heat, which suddenly expands the air, causing it to be highly rarified at the point of explosion. The air immediately surrounding it is driven violently outward in every direction. The first layer of air-particles, surrounding the bubble, is driven against the second and then swings back to its place, for the force that drove it outward is no longer present. The second layer swings against the third and the third against the fourth, and so on; each layer after making its excursion outward returns to its original position. The air-particles are not fired at the ear as from a gun; they simply vibrate to and fro. The sound-pulse moves outward like an expanding globe at the rate of about 1,100 feet per second in air, the speed depending upon the medium through which it travels.

Some notion of the movement of a sound-pulsation may be had by watching the expanding ring made by a pebble when dropped into a pond of smooth water. A still clearer idea may be had by laying a number of billiard-balls in a groove, so that they are in close contact. Now tap on one of the end balls sharply and watch the effect. None

of the balls seem to have changed position except the end one, opposite from the one that received the blow. This one has rolled away from the others. The first ball struck delivered its blow to the second, and so on to the last. This one, having nothing to deliver its blow to, rolls away under the impetus given to it by the ball next to it. This is precisely what takes place in the air, only with balls infinitely small, as compared with the billiard-balls. Each ball has made a pendulous motion; it has moved forward a short space and returned to its original position. The distance it has moved forward and back is called the amplitude (largeness—size) of its motion or vibration, and, other things being equal, the loudness of a sound varies as the square of the amplitude of the vibratory impulse.

Starting again with our soap-bubble, from the point of explosion: the same impulse moves in every direction—like light from a single luminous point—through the air, but produces no sensation till it strikes an ear. The membrane of the ear is made to vibrate or swing back and forth, which, in turn, moves the inner mechanism of the ear—for it is a mechanism, and a most wonderful one—which finally communicates its motion to the auditory nerve, which reaches into the brain, where the motion is translated into a sensation that we call Sound. What is this mysterious

blending between the activities of the outer world and the sense-perception of the inner consciousness? All the combined wisdom of philosophers and sages has never solved the problem. Much has been written, but no explanation, only words, words, words. We have to be satisfied with studying the phenomena only, of natural law, for that is all we can really know about it. We perceive the facts, but cannot explain how the physical is translated into mental consciousness.

Sound is transmitted either through gases, liquids, or solids, but the velocity is determined by the elasticity of the medium through which it is transmitted. Numerous experiments have been made to determine the velocity of sound when transmitted through different media, and long tables on this subject may be found. The following table will give a general idea of the velocity of sound through solids, liquids, and gases:

The velocity through air, 1,100 feet per second.

The velocity through water, over four times that of air.

The velocity through pine-wood, ten times that of air.

The velocity through iron, seventeen times that of air.

x

These figures are only approximately cor-

rect, as the velocity of sound in gases varies with changes of temperature. Again, a loud sound travels faster than a feeble one. A striking instance of this fact is shown in an experiment made by some Arctic explorers. Sounds, even moderate ones, are heard to comparatively great distances over smooth ice. A cannon was fired, and the observer, who was quite a distance from the gun, heard the boom of the cannon before he heard the order to fire, which, of course, was given first.

Sound cannot be transmitted through a vacuum, as shown by the following familiar experiment made by a philosopher named Hawksbee as far back as 1705. Place a bell that is operated by a clock-work inside of the receiver of an air-pump. This receiver is a large bell-glass, ground to make an air-tight fit on the bedplate of the air-pump. Suspend the bell inside the receiver, by some kind of cord that will not transmit sound, and then set it to ringing. At first it will ring as loudly as though it were in the open air. Now, work the pump and exhaust the air. The sound will grow fainter until a nearly perfect vacuum is obtained, when the sound will cease, although the hammer is still striking the bell the same as at first. Now let the air in and the ringing is heard again.

Reasoning from the above experiment, one should expect that sounds would not be as

loud on high mountains as down on the sea-level. This is found to be the case, because the air at very high elevations is much less dense and there are fewer air-molecules in a given area to strike upon the drum of the ear.

For the same reason sound will be carried farther and seem louder on some days than others. When the barometer is high it shows that the air is dense, and dense air is a better medium for sound-transmission than rarified air, at least so far as loudness is concerned. The experiment with the bell in a vacuum shows that sound is transmitted only through material of some kind that may be made manifest to our senses. It also shows that matter, as we understand it, is not necessary for the transmission of light and radiant heat, for both light and radiant heat will pass through the vacuum, when the bell will not sound, as readily as through the air. These latter subjects will be taken up under another head in some future chapter.

Sound is reflected like light. It may be focussed on a single point, like light or radiant heat, by means of concave reflectors. It tends to move in straight lines, but will in a degree go around an object; yet a large object casts a distinct sound-shadow, if we may use the term. If we throw an elastic ball on the floor with considerable force it will rebound at the same angle at which it was moving when it

struck the floor. The direction it was moving before it struck is called the angle of incidence, and the direction it moves after that is called the angle of reflection. Sound and light obey this law. Sound-waves are reflected from a polished surface the same as light-waves, and they obey the same laws in the matter of focussing and dispersion that light does.

A striking instance of sound-reflection may be noticed any time during the passage of a thunderstorm. Whoever has stood on a mountain-top towering 15,000 feet above the sea and from this view-point of a cloudless sky and bright sunshine has looked down upon a storm-cloud hovering far below against the side of the mountain, and stretching far across the valley, has witnessed a scene of grandeur that no language can adequately describe. It is from a view like this that one gets an accurate conception of cloud-form as it really is. Great billowy mountains, whose crests are tipped with purest silver and whose shapes are as multiformed as the leaves of the forest and as numberless as the sands of the desert!

A storm-cloud as seen from above, under the full rays of the sun, appears to be, and doubtless is, made up of a series of clouds that may or may not touch each other. During the progress of the storm one or more of the clouds becomes surcharged from time to

time with electricity, when it seeks to establish an equilibrium, by discharging into the earth or into another cloud. This discharge causes a great sound-wave to flow out from the point of disruption, much louder than the booming of the heaviest cannon, and it travels, as we have seen, at the rate of 1,100 feet per second through the air in all directions. Suppose we are standing one mile from the point of disruption in the cloud, watching the operation of nature's great electrical power-plant. We see a flash of lightning, and in a little less than five seconds we hear the thunder; and, although there has been only a single report like the firing of a cannon, it seems to us to be a great many following each other in rapid succession. We have already seen that a sound-wave moves out like an expanding globe from a common center, which is the origin of the sound-impulse. A part of the wave coming from the cloud moves in a direct line toward the observer. When the wave strikes his ear there is the sensation of an explosion of great power, and this is followed by others in rapid succession, for several seconds, each succeeding one growing weaker until it dies out in what seems to be a distant roll of thunder. The explanation is this: Beyond the cloud where the discharge took place, and farther away from the observer, is another cloud with a large reflecting surface,

and beyond that a second, a third, and so on, it may be, for many miles. Each one of these surfaces reflects back to the ear of the observer a part of this great sonorous impulse; but as a part of the wave that is reflected, is reflected from the successive cloud-surfaces that are farther away, and no two of them the same, the reflected sound keeps on coming to the ear at disjointed intervals, because the distances are constantly increasing and not uniform. If the first cloud beyond the point of explosion is 550 feet farther away from the observer, the second explosion, or the first reflected explosion, will occur one second after the first; for it has to travel 550 feet away, and then retrace the distance. So, by that time, the original wave will have one-fifth of a mile the start. This is the cause in many instances, and the chief cause in most cases, of the phenomena of rolling thunder. There are many other reflecting surfaces in the air, however, besides clouds; and this leads us to the further discussion of this same subject in our next chapter.

CHAPTER VII.

ECHO AND RESONANCE.

In our last chapter we discussed the subject of reflected sound, which is only another name for Echo, and when we have reached the subject of musical sounds it will appear again under the head of Resonance.

When I was a child I grew up among the hills of southeastern Ohio. I well remember going often to a certain spot among the hills to have a "scrap" with another "naughty" boy, who lived or seemed to live, away up among the hills, a long way off. In my childish imaginings I could see him hiding behind some crag or hillock and only showing his head long enough to throw back in perfect mimicry my own words with the most unwearying promptness. There were more than one of these spirits; in fact, a whole family of them. They seemed to be brothers, for they all spoke with the same quality of voice. Each one, however, had to be spoken to from a different point. The only difference seemed to be that one of them was very prompt and loud in his mimicry, almost catching the words out

of my mouth before they were spoken, while another was more deliberate and seemed to take time to consider before sending back his saucy message, and when it did come it was not spoken in so loud a voice as the first boy seemed to have.

When I grew older I learned something of the laws of sound, and then I understood why I never could call my imaginary boys from their hiding-places. I learned that all this mimicry was simply a reflection, or an echo, of my own voice, and that the quick, loud voice came from the reflecting surface of a hill near by, and that the one slower to respond and not so loud was a reflection from a hill at a greater distance from me. I learned this lesson: If you say nothing your words cannot be thrown back at you. Or, as the Arab proverb has it: "Of thy unspoken word thou art master; thy spoken word is master of thee."

I once stood in the base of the dome of St. Paul's, London. I stood with my face to the wall while a friend stood with his back to me on the opposite side of the dome, also facing the wall. In this position we could converse with ease in a whisper. This was caused by a series of sound-reflections that passed around each inner half of the dome and met exactly opposite to the point where the speaker stood. The sound was concentrated where the listener

stood, somewhat in the same manner as though spoken through a speaking-tube. In one of the large dome-shaped rooms at the capitol at Washington there are two points on the floor where two persons may stand and converse with ease, in a very low voice, though some distance apart. If one person moves a few inches out of position the conversation cannot be heard. The ceiling in some way makes two focal points the same as two parabolic mirrors will for light or radiant heat as well as for sound. In fact, the flight of sound is governed by the same laws as that of light in almost, if not quite, all respects. It is reflected and refracted, condensed and dispersed, the same as light.

Sounds may be distorted by this law of reflection till there is no resemblance between the original sound, as it would seem to one who was near by its source, and as it would seem to one who was off a considerable distance, and so situated as to get reflections of the original from many points, differing not only in distance, but in the character of the respective reflecting surfaces. Almost every one has seen himself or herself in one of those curious mirrors so made as to produce a distorted image of whatever is reflected. By keeping this in mind you can get a mental picture of what takes place when sounds are distorted.

A minister once told me an amusing story

of how a young man was called to preach by one of these distorted sounds. He did not feel quite sure of his call, so he submitted his case to what he thought would be a crucial test. He lived in a country of high hills and sinuous valleys. He betook himself to the fields, far away from human habitation, and here he prayed, that, if the Lord wanted him to preach He would give him an audible sign of no uncertain sound. His prayer was answered in the affirmative almost as soon as uttered, in a most pronounced and astounding way. There came to his ears a most unearthly sound, unlike anything that had ever come within his experience, and he went home with a clear-cut conviction respecting his duty as a future minister of the Gospel. Upon investigation it was found that over in one of the valleys there was quietly grazing one of those long-eared, four-footed animals so noted for their wonderful vocal powers. Just as the young man had uttered his prayer the animal —as if in answer—spoke to the hills as only such animals can. The hills played tennis with his voice. It bounded and rebounded from rock to crag and crag to peak and from a thousand other reflecting surfaces until the voice—not lovely at its best—was twisted and distorted into a thousand hideous combinations of all that was unlovely, uncanny, and horrible, by the time it reached the ear of the

young seeker of a sign,—and, because it was unnatural, he concluded that it was supernatural.

Resonance (re-sounding) is really echo; but the term applies to echoes, or sound-reflections, only when the time between the original sound and the reflected sound is practically nil. The intervening space of time is so short that the original and the echo-sound seem to sound in unison. The result is that the sound as a whole is vastly increased. and enriched. Makers of musical instruments take advantage of this phenomenon of resonance, which is the chief factor in giving the quality of tone that belongs to any class of musical instruments. The pipe of the organ, the sound-board of the piano, and the body of the violin are all used to take advantage of this law of resonance.

Bodies of air inclosed in any way, as in a tube, or in any other form, have a certain rate at which the inclosed air will vibrate in sympathy with a tone, the vibration-rate of which is the same as the fundamental or natural rate of the inclosed air-body. It will be observed that air-bodies when inclosed follow the same law as solids in that they have a fixed rate of vibration when set in motion. If we take a tube, say sixteen inches long, closed at one end, and a tuning-fork that vibrates at the rate of 256 times per second, and bring them together so that the vibrating-fork

will be over the mouth of the tube, the sound of the fork will not be increased to any extent. Now, excite the tuning-fork again and gradually fill the tube with water. When it reaches a point thirteen inches from the top, or open end, of the tube, a full tone, not unlike that of an organ-pipe, will be heard. It will be seen from this experiment that the fundamental rate of vibration of a column of air in a tube closed at one end, and thirteen inches high, is 256 vibrations per second.

Organ-pipes depend wholly upon their resonant quality for the peculiar individuality of tone that they possess. Any vibrating body having a rate in unison with the fundamental air-column in the pipe will cause the pipe to sound. The exciting body may be held over the open end of the pipe or placed at a narrow opening at the stopped end of the pipe. Some organ-pipes are made to sound by a reed —a thin tongue of wood or metal vibrated by the blowing of air upon it—and others by a jet of air blowing on a feather-edge in a narrow opening at the closed end of the pipe, like a boy's whistle.

The resonance of a piano comes from the sound-board and not from confined air-bodies. The board is so constructed as to be sympathetic to any rate of vibration that the various strings are capable of transmitting

to it. If a string is vibrated alone in the air the sound is very feeble, but whe strained over and, at its ends, in contact with a suitable sound-board, the sound is loud and distinct, because the board which vibrates in sympathy with the string presents a large surface to the air, and therefore moves it with much greater energy than it is possible for the string to do, which presents only a small surface to the air. The same is true of the violin, only in a much greater degree. The violin, when perfectly made, has all the variety of gradation in pitch of the human voice. It combines the resonance of both the sound-board and the air-cavity.

I once went under one of the falls of Niagara. The water descended from an overhanging rock, leaving a great cavern between the fall of water and the rock back of it. There were rocks piled up in front of the section of the falls that I was exploring, so that it was possible to pass around in front, as well as to go in behind it. The difference between the roar when outside and in front and that experienced when back of the fall was something wonderful. Inside, it seemed as if all the pent-up thunders of the universe were turned loose, and the noise was deafening. I observed the same phenomenon when crossing the River Reuss in Switzerland at a

point called the Devil's Bridge. The river at that point plunges over a precipice into a cavern. The vibrations that are set up in the cavern produce the effect of loud thunder.

CHAPTER VIII.

SOUND-SYMPATHY.

All solid substances tend to swing or vibrate at a certain definite rate, like a pendulum. A tuning-fork that is tuned in exact unison with the piano-string called middle C, will vibrate only at the rate of 256 times per second when excited. A clock-pendulum that is the right length to swing to and fro once in every second of time will only swing at that rate, if left to itself. If the length is increased it will oscillate at a slower rate, and if the length is decreased it will swing at a faster rate. If a wire of a given length and thickness is stretched between two points the rate at which it will vibrate will depend upon the strain that it is under. The more it is stretched the more rapidly it will vibrate, when plucked or excited with a bow. The pendulum follows a different law. Its rate of vibration is determined wholly by its length and not by its weight.

If we quadruple the tension of a string its pitch will be raised one octave. If the tension remains the same as well as the length, and

the string is made double the thickness, the pitch will be lowered one octave. A building or any kind of structure has a rate of vibration that belongs to it alone if force enough is applied to set it swinging. So it is with all solids; each separate body has a rate of motion that belongs to it alone, and this rate is called the fundamental. When a stretched cord vibrates as a whole, it is giving its fundamental rate of vibration, and will continue to vibrate at that rate when excited so long as the strain remains the same. Air not confined will vibrate at one rate as well as another on account of its mobility.

The diaphragm of a speaking-telephone—the thin membrane against which the voice strikes, causing vibrations which are transmitted along the wire to the other end—is so made as to have as little as possible of this fundamental quality, and to partake as far as possible of the properties of the air; because to be a good telephone it must be able to take one rate of vibration as well as another. If we stretch two cords on the same frame and bring them into exact unison, so that the fundamental of each will be the same, and then excite one of the strings, the other will vibrate in sympathy. If, now, we raise or lower the strain of the sympathetic string it will no longer vibrate for the other string. The same phenomenon will occur be-

tween two tuning-forks that are tuned exactly alike. If a fork is mounted upon a suitable resonating-box and then set in vibration by means of a violin-bow, it will give out a pure musical tone. If, now, we take an exact counterpart of this fork, mounted in the same way, and set it to sounding for a few seconds and then stop it, the other fork will be heard sounding the same note, in sympathy. If we load the one sounding in sympathy, with a piece of wax, and then repeat the experiment, the fork that before was sympathetic will now be dumb, because it is out of tune with its mate.

As you know, sympathy is not confined to strings and tuning-forks. It is just so with men. When they are out of tune with their surroundings they are not sympathetic with their fellows.

If we place two clocks on the same shelf and adjust their pendulums to swing in exact unison and set one of them to running, in the course of time the other will start up in sympathy. Each sound-impulse, caused by the vibration of the pendulum of the clock that is running, is communicated to the other pendulum. Each successive impulse adds to the swing of the sympathetic pendulum which began in an exceedingly small way at the very first stroke of the initial pendulum, and this goes on until the sympathetic pendulum is

making its full stroke. The same is true of the sympathetic tuning-forks. Each air-wave that is sent out by the initial fork strikes the other fork and causes at first a slight vibration which accumulates, because each successive air-wave strikes the sympathetic fork just at the end of its swing and works in harmony with the natural tendency of the fork to vibrate. The result is a co-operation. Each helps the other.

How much better it would be for the world if men would take pattern after this law of physics!

If now we load the sympathetic fork, as before mentioned, so as to throw it out of harmony with the initial fork, it ceases to be sympathetic, because each is working against the natural tendency of the other to vibrate at its own fundamental rate. When an army crosses a bridge the soldiers are required to break step. The tramp of hundreds in unison if kept up long would endanger the bridge, especially if the fundamental swing of the bridge should happen to be in time with the step of the army. If we should determine the natural rate of swing of a high building and find that it made an excursion to and fro like a pendulum once in five seconds, and then should fire a cannon at some distance not far away exactly once in five seconds, each air-wave would strike the build-

ing just at the right time to co-operate with the natural or fundamental rate of the swing of the building, and would thus increase the oscillation to and fro at each boom of the cannon until the building could no longer endure the strain, when it would come down with a crash. Such is the power of co-operation, which works in obedience to a law that runs through the physical, the commercial, and the moral world as well.

The particular lesson to be drawn from this chapter is: Never try to accomplish your ends by working against some fundamental law. Many littles exerted in the right direction become a great power. This same exertion in the wrong direction is swallowed up and lost by opposing forces.

CHAPTER IX.

NOISE AND MUSIC.

In the preceding chapters we have considered sound only from the standpoint of a single pulsation. We will now consider it in its composite character. It is rarely, if ever, that a sound-impulse is transmitted singly. If we watch a water-wave we never see it alone. Smaller waves are superposed on the larger ones, and yet still smaller ones on the next larger and so on. This phase of the subject will be discussed under the head of overtones, farther along. We have now to consider the physical distinction—outside of ourselves—between noise and music: we know the distinction as a sensation; every one does. We know that noise is irritating to the nerves, producing a series of unpleasant and irregular shocks. The more irregular and disjointed the sounds are, the more unpleasant the sensations. All have experienced the unpleasant effect of an irregular, flickering light. If we could see the moving mechanism of these irregular sound-waves they would affect us unpleasantly through two avenues to the

brain, namely, through the eye as well as the ear.

If we should throw a lot of nails, scraps of metal, stones, and other hard substances into a barrel and roll it, we should hear noise of a very unpleasant kind. But if we could arrange these noises or irregular sound-impulses into a certain order of succession, we should have musical tones instead, that would be pleasing to the ear. Musical sounds are single sound-impulses that are repeated in a certain o-der of succession. The time between the successive sound-impulses must be the same. There must be perfect periodicity. For instance, a certain string of the piano, called middle C, vibrates at the rate of 256 times per second when struck with the key-hammer corresponding to it. (In England a "vibration" is a movement to and fro. In France, it is one movement either to or fro.) Every vibration makes an air-wave that moves out into space at the rate, as we have seen, of about 1,100 feet per second. These vibrations are divided into equal periods and they succeed each other at the rate of 256 times per second. Therefore the time between one sound-wave and another is one two-hundred-and-fifty-sixth part of a second.

If we should take one of the pieces of metal out of the barrel referred to, and tap it at the rate of forty times per second on the side of

the barrel, and have all the taps exactly one-fortieth of a second in time apart, you would hear instead of a noise, a musical tone. If a locomotive should puff forty or fifty or more times per second, and in equal periods, it would announce itself with a musical tone of wonderful power. If the clap of thunder spoken of in a previous chapter should be repeated from a succession of clouds that were near enough together and exactly the same distance apart, instead of the rumbling, explosive sounds we hear we should experience the sensation of a musical tone transcending in power anything that we can imagine. If the noises of the streets of a city could be arranged in order we might have from them orchestral music instead of disjointed and disagreeable sounds.

I once stood under the long arch of an aqueduct some miles above Washington City on the Potomac. The structure was that of a long, low arch made of cut-stone. The stones were of equal thickness, and at the joints they were beveled so as to form a V-shaped groove from two to three inches deep. Standing under and at one end of the arch, one side of all the grooves were facing me and formed sound-reflecting surfaces. I clapped my hands together to get the echo from the abutment at the opposite end, and was surprised to hear first a musical tone of short duration and

then a complete reproduction of the sound as I heard it when I clapped my hands. The explanation is simple when we consider the nature of the structure. The reflecting surfaces were equidistant from each other, and therefore the echoes came back to me in rapid succession of equal periods, at the rate of 100 or more per second. Hence the musical tone. Sounds of all kinds may be rendered musical by following the law laid down in this chapter, to wit: By making them with perfect periodicity.

But there are different phases of musical sounds, and one of these is called pitch. Pitch is simply the rate of vibration per second of a musical tone. Some of the largest organ-pipes are pitched as low as sixteen vibrations per second. The ear can distinguish the separate pulsations at that low rate, but when the vibrations reach the rate of thirty or forty per second they cannot be distinguished separately, but produce the sensation of a continuous sound. The ear has the quality of the eye, that is called persistence of vision. The conscious sensation does not stop as soon as the external air-vibrations do, which have produced that sensation. That is, the sensation lingers for a fraction of a second after the external sound has ceased.

This persistence of sound-sensation is sufficient to bridge over the short space occurring

between the sound-pulsations, and thus produces the effect on the hearer of continuous sound. The air is so constructed as to take all tones between sixteen vibrations per second and from 30,000 to 40,000 per second. Some ears have greater range than others. That is to say, some people can hear a musical tone with a rate of vibration equal to 40,000 per second, but others fail to hear soon after 30,000, while the average person cannot hear a tone above 38,000 vibrations per second. Motion does not stop at this limit. It keeps on in one medium or another and would be sensible to other beings endowed with a better and longer range of hearing and a keener sight. While vibration ceases to affect our senses at 40,000 per second, as sound, we find ourselves conscious again of periodic motion when it reaches 400,000 billions of times per second; then we hear with our eyes or see with o r ears, whichever you choose. The sensation is, in all cases, the effect of motion.

There is much food for speculation in the thought that there exist sound-waves that no ear can hear and color-waves of light that no eye can see. The (to us) long, dark, soundless space between 40,000 and 400,000,000,000,000 vibrations per second, and the infinity of range beyond 700,000,000,000,000, where light ceases, in the universe of motion, makes it

possible to indulge in the speculation that there may be beings who live in different planes from ourselves and who are endowed with sense-organs like our own, only they are tuned to hear and see in a different sphere of motion.

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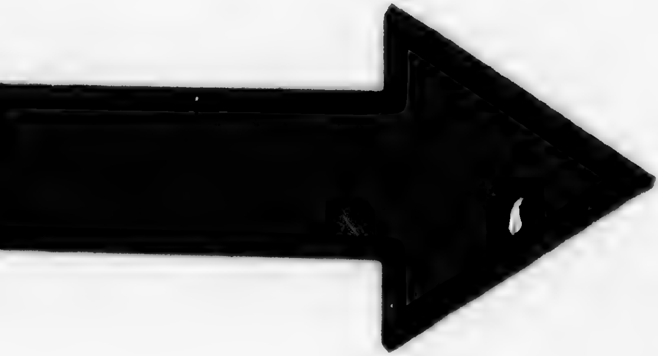

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CHAPTER X.

MUSIC AND MUSICIANS.

Music is the language of emotion. It does not consist wholly of tones varying in pitch and quality, arranged in a certain order of succession that we call a musical composition. These tones are, however, a necessary part, and may be termed the mechanics of music, or the means through which the emotions of the player or singer are conveyed to and impressed upon the soul of the hearer.

There are hundreds of thousands of people who drum upon the piano, who saw upon the violin, and pick the strings of a mandolin or banjo, and many do it with perfect technique, but there are very few musicians in the highest sense of the term. Musicians in this high sense are like poets, born, not made. Music has many definitions. It may be purely subjective and heard only in our own dreams at night, or in certain exalted moods of our waking hours. Pythagoras had a notion of music that he called "the music of the spheres," which was unheard by mortal ears. To his imagination the seven planets in their

movements gave out musical tones corresponding to the seven notes of the musical scale. What a grand conception! We speak of the music of nature, the sighing and sobbing of the winds, the lapping of the waves, and the song of birds, but these sounds, disassociated from their settings, would have but little of music in them. When we hear the wind, in our imagination we see the flutter of green leaves, the swaying of pine-boughs, the waving of grain-fields, and a thousand other pictures of nature. The associations of happy childhood come trooping into our minds and arouse a poetic feeling in our souls. Or, when sitting on the shore of a great lake, unruffled by boisterous winds but reflecting from its smooth surface a thousand varying cloud-tints, and you hear the lapping of the wavelets on the pebbly shore; a great song wells up in your soul which soothes and quiets you. But the lapping of the waves, disassociated from the beautiful coloring of the smooth water, would have little of music in them.

While the notes of some birds are very sweet and pure in themselves, they never utter what could be called a musical composition, even of the simplest kind. The music of birds consists largely in their own beauty and the beauty and grandeur of their surroundings. Take away their bright plumage, the green trees, the many-tinted flowers, which in them-

selves are a poem of color; the mere sounds, stripped of their surroundings, although in many cases agreeable, cannot be said to be musical.

> "The lark sings high up in the air,
> The linnet on the tree."

Poets have sung the praises of the lark, but in fact there are many birds with sweeter notes that have lived and died "unwept and unsung." The lark, because he "sings high up in the air," and his notes come to us faintly, arouses in us that wonderfully creative machinery of the soul called the imagination; and this is how "distance lends enchantment."

The common definition of music is that it consists, subjectively, of pleasurable emotions produced by melodious and harmonious sounds and, objectively, it is a composition made up of musical tones, differing in pitch, so related in their order of succession and in their combinations as to produce the sensation of harmony or melody when the ear carries it to the brain. The musical scale, or gamut, consists of seven notes differing in pitch—that is, differing in the number of vibrations per second composing the notes of the scale. The relation between the different notes of the diatonic or natural scale, as expressed in vibrations, may be stated as follows: If we call

the first note (the one lowest in pitch) 1, we may express the names and ratios thus: Names C, D, E, F, G, A, B, C; Intervals, 1st, 2d, 3d, 4th, 5th, 6th, 7th, 8th; Rates of vibration, 1, $^9/_8$, $^5/_4$, $^4/_3$, $^3/_2$, $^5/_3$, $^{15}/_8$, 2. The eighth note is called the octave, and has just double the number of vibrations per second that the first note has, which is an octave below. For instance, if middle C has 256 vibrations per second, the eighth note, or the first octave above, will have 512 vibrations per second, and the intervening tones will bear the relation expressed by the fractions. The eighth tone will be the first note of the repeated octave. The natural scale is made up of five whole tones and two semitones, but there is also a scale made of twelve semitones, called the chromatic scale; so that a musical composition may start with different ones of these semitones by a system of transposition. The starting note is called the keynote.

We cannot in a short popular chapter, without cuts and diagrams, go into all the intricate factors involved in a musical composition. We can only give such general ideas of the mechanics of music as will enable us better to understand its meaning and its bearing upon everyday life. As we said in the beginning, music is the language of emotion, and these tones and semitones are but the tools in the hands of the musician to give

expression to his emotions as they arise in his own soul. The same musical composition may be rendered in a great many ways, according to the mood of the player or singer, and none of these renderings may have been in the mind of the composer. He may have been trying to give expression to an entirely different set of emotions. How these conflicting and ever-changing emotions can be conveyed from the inner soul of the musician to the ear and thence to the consciousness of the listener we will endeavor to explain.

We now come to the most intricate and at the same time the most important phase of sound-vibration. I have already said that perfectly pure tones are rarely if ever heard. If we stretch a cord or wire and vibrate it as a whole it also vibrates in its aliquot parts (parts which will divide it without a remainder). The vibration as a whole is called its fundamental. If a cord vibrates as a whole and also in halves, forming a nodal point (a fixed, unvibrating point) in the center of the string, there would be a composite tone; the string as a whole will be vibrating at the rate, say, of 100 vibrations per second. The two halves will be each vibrating at the rate of 200 per second. The lower tone will be the one that determines its pitch, and the others that are superposed on this foundation-motion will simply determine the quality of the fun-

damental tone. If, now, the two halves are subdivided into a shorter set of superposed motions the quality of the fundamental tone will be changed again. Those superposed vibrations are always higher in pitch and, if musical, bear a harmonic relation to the fundamental tone. Thousands and thousands of these superposed tones may be added to a fundamental tone, and each added one changes the quality of such fundamental. These superposed tones are called overtones. The effect they produce is called, in English, "quality"; in French, "timbre" (stamp, or character); in German, "Klangfarbe" (sound-tint), a very expressive word when we consider the relation of sound mixtures to light mixtures. We mix colors to get different tints, and later on we shall see that for sound we are only mixing vibrations of different rates per second; color is as much vibration as sound. If we mix sound-vibration we are simply getting sonorous tints that affect the brain through the ear very much as it is affected by mixtures of color through the eyes.

It is said that some voices that are very rich in overtones contain as high as 30,000 of these accompanying tones. No two voices are alike, and the difference is what is called a difference of quality; and this quality is determined by the ability of the vocal organs to produce a greater or less number of over-

tones coupled with the varying pitches of the different voices. If you hear a violin, although you do not see it, you have no hesitancy in asserting that you do hear one. If you hear an organ under the same circumstances you are just as sure that it is an organ as you would be if you should see it at the same time. The same would be true of a piano and many other musical instruments. Why? Because each of these instruments has different sets of overtones and therefore a different quality, which gives to each an individuality. The identity of the different instruments has been established as thoroughly as though the hearer had seen them as well as heard them and through the same general medium, motion. Of course, if he never had seen them, the sound alone would not convey to him the idea of their form.

So far as we are able to determine, sound-quality possesses differences that are infinite in number.

Musical instruments are limited in their powers of expression much more than is the human voice, but, like the human voice, there is a great difference in the same kind of instruments. For instance, violins that are very old, have been made by masters of the art, and have been used a great deal, often command fabulous prices because of the rich quality of their tones. If they are made as

they should be and out of the best material they still improve by use, just as the human instrument improves by practice. But no instrument, however perfectly made, equals the human voice in its ability to express emotions, for the emotion produced by the playing of an instrument comes primarily from the player himself. The human vocal organs in their power to express all kinds of emotion, through the medium of vibration, transcend all other mediums for producing sound-quality. Emotions through these organs are impressed upon the air in the shape of vibrations in the most intricate combinations, so that every vocally expressed emotion has its correlative in the surrounding atmosphere as a moving form or shape. When a player or singer gives such a rendering of a musical composition as to cause a profound emotion to sweep over his audience we call him an artist. He puts his soul into the rendering and that moves our souls. Another may play the same composition with even better technique and yet it is a dead, cold, mechanical performance. It is as devoid of feeling as the music-box or the orchestrion driven by a spring or weight.

I once heard a street singer who had a fairly good voice but wholly uncultivated. She sang in a manner that showed she had in her the soul of a true artist. Her words were in

a foreign tongue, but that made no difference; she told her story more effectually because the words could not be understood, but left the imagination to supply them. No words have ever been invented that will convey the sensation of a profound emotion so well as the language of music—when it really is music. She did more than sing a song; it was the plaint of her own burdened soul "floating away on the wings of melody." She moved me profoundly. It was not her personality, for that was unattractive. She would have moved me more profoundly if I had not seen but only heard her, for then my imagination would have given to that wonderful rendition a more appropriate setting. She moved me by impressing a moving picture of the emotions of her burdened heart upon the surrounding air by throwing it into a peculiar form of motion, and this motion was conveyed to my brain through the organs of hearing and there translated into emotion. What a wonderful mechanism is the human vocal organ, and what wonderful powers of expression it has when it is the servant of a profound emotion! What a wonderful mechanism is the human ear to be able to pick up and translate with fidelity all the fine shadings of such a wonderfully complicated air-impression!

The artist's power of rendition will be modified by the occasion and by his surroundings

at the time. A funeral hymn cannot be rendered with full effect except at a funeral. Our national hymn, "My country, 'tis of thee," never sounds so well or stirs the feelings so profoundly as on some extraordinarily patriotic occasion. Sometimes a singer is so great an artist that he can create the occasion, by leading the audience away from their real environment and, for the time, make them feel that they are surrounded by a set of conditions that do not really exist. He carries them away on the wings of their imaginations and puts them under the spell of his own magic and plays upon their emotions at will. A man, to do this, must really be a great artist, and possess a power that few men are gifted with.

While the composer of a musical composition is an important factor, he is not the only or even the greatest factor, when measured by its effect upon the people at the time of its rendering. The artist and the occasion are greater factors. Every one can recall occasions when some simple musical composition has produced a profound emotion simply on account of the circumstances under which it was played or sung. I remember an incident in my own experience that, ever since, has seemed to me to have been the most thrilling moment of my life. On the 9th of July, 1881, I sailed from New York for Glasgow

on the steamer *Circassia* of the Anchor Line. All who are old enough will remember that only a few days before that time not only our country but the whole civilized world was shocked by the shooting of President Garfield at the hands of an assassin. At the time the steamer sailed his life hung, as it were, in a balance, no one knowing at what moment the scales would turn, or which way. Imagine if you can a ship-load of people, all deeply interested, shut up for ten days without any means of communication with the outside world during that time. Not only shut up, but shut up with a feeling of anxiety and suspense, that grew from day to day and was intensified by being enveloped in an atmosphere of the same kind of feeling that found expression in word and look.

One beautifully clear morning, after we had been out some eight or nine days, we found ourselves sailing in smooth water, close to land on the north shore of Ireland. All the people were on deck and all were alive with expectancy balanced between hope and fear, for we knew that in a short time we should have news from home—thanks to the business energy of such men as Cyrus W. Field and the scientific ability of a Lord Kelvin. All nationalities were represented on the deck of that steamer, as we rounded a point of land at the entrance to the harbor of Moville.

There were English, Irish and Scotch, French and German, and at least one Italian cripple, who was going back home to the land of sunshine and song, together with many Americans. All eyes are looking wistfully toward the shore, as if trying to solve the problem, through some sign, when, lo! a boat with two uniformed men, is seen coming off from the signal-station, at the entrance of the harbor, and steering directly for our ship. When they came within hailing distance one of the men stood up in the boat, and making a funnel around his mouth with his hands, shouted the words, "Garfield all right."

Silence reigned for a moment, while such a wave of profound emotion swept and surged through that throng as rarely ever stirs the souls of men. Every face was tense with feeling, and the tears started from all eyes—even from those of the Italian cripple. For one supreme moment national boundaries were obliterated, and all were brothers with a common feeling of sympathy, centered upon the stricken President of the greatest republic on earth. One moment of silence, more eloquent than the most impassioned speech, and then the multitude found its voice, and such cheers as went up from the deck of that steamer! Then the doxology, "Praise God, from whom all blessings flow," burst spontaneously from the lips of the throng; and such music!

Hundreds of times had I heard this same doxology, but this was the first time I had felt its real meaning. It was the first time I had ever really heard it sung understandingly, and it has had a new meaning ever since. Such is the power of circumstance and environment. In all probability this was the only occasion of a lifetime when I shall, except in memory, hear such an impressive rendering of the old doxology, familiar, in a way, to all Christendom,—but how few have ever really heard it!

CHAPTER XI.

SOUND-INTERFERENCE.

We have seen by the preceding chapters that sounds may co-operate with and re-enforce each other. We have seen also that sounds are sympathetic and that bodies will vibrate in sympathy with other bodies that have the same natural rate of vibration, and that they tend to help each other to prolong the sound. It is a law of tones that those which are concordant tend to prolong their time of sounding, while discordant notes tend to kill each other. These facts go to prove the theory of the "survival of the fittest." If two equal forces oppose each other the result will be nil.

If we could see the sound-waves in the air we would see that they were made up of a series of air-condensations and rarefactions, and if the waves are those of a musical tone the distances between the centres of the condensations will be the same. If the pitch changes the distance between them (or wave-length) will change, but they will still be equidistant.

Suppose we sound two tones from the same

point of departure—or as nearly so as possible—and that both are exactly the same loudness and exactly the same pitch—which means the same number per second. If both are sounded coincidently, so that the condensations and rarefactions occupy the same space, the effect will be a loud tone, because the one tone augments the other. If we stop one of the tones the effect will be a weaker tone of the same pitch. If we could now set them to vibrating, so that one could be a half vibration ahead of the other, then the condensed part of the wave of one tone would occupy the space of the rarefied part of the other, and the result would be no sound at all, although both tuning-forks, or other sounding sources, are vibrating as intensely as in the first case, where there was a coincidence of condensations and rarefactions. Thus it will be seen that sounds may help each other or they may kill each other.

Suppose that the waves are running high on the lake, and that we could have a set of inverted waves that would exactly fit in the depressions between the crests of the lake waves: the result would be smooth water. So when one set of sound-waves fits into those of another, like the cogs of a wheel, the result is smooth air and consequently no sound.

Musical sounds are the only ones that can be so related as to produce perfect silence,

from two sounds that are in perfect unison. Irregular or discordant noises are constantly interfering with each other and killing one another so that the sounds of the streets are very much subdued by the operation of this law. If it were not true, street and other noises would become unbearable.

Most of us can remember, when we were children, of having a shell held to our ears, so that we could hear the "sea roar." If we hold almost any small cavity to the ear a roaring sound is heard. This is due to resonance, the phenomena of which is discussed in a preceding chapter. Little ghosts of sounds that have been killed to ordinary hearing are made sensible by resonant re-enforcement, when a cavity is held to the ear. Any one can try the experiment. If the cavity is adjustable it will be noticed that the smaller the cavity the higher the pitch of the roar. This is as one should expect, as we have seen that all air-cavities have a fundamental that is awakened when a unisonant sound comes to it.

The ghosts of sounds of all pitches are floating in the air and those only will be re-enforced, so as to become audible, as are in unison with the pitch or fundamental of the cavity, whatever it may be.

Some years ago the writer constructed an apparatus that illustrated beautifully the

phenomena of sound-interferences. It was an electro-acoustic apparatus and was constructed as follows: The receiver of the sound was simply a tuned reed, like one prong of a tuning-fork, and made to vibrate by an electro-magnet, mounted in front of the reed. This reed was mounted finally on a resonating-box of wood, the same as used for mounting tuning-forks. The air-cavity was of such size as to re-enforce the vibrations of the reed, and so the two were in unison. The two ends of the magnet-wire were connected with leading wires that ran into another room and there connected to the two poles of a battery of, say, twenty cells. At the battery were two other reeds, tuned in unison with the reed at the receiver. The transmitting reeds were kept in constant vibration by a battery and magnet with self-breaking apparatus. Each reed vibrated ten cells, or one-half the battery, so that each was using the same power.

I said that the two transmitting reeds were in unison. They were not quite so; one of them would gain a vibration once in about five minutes. The vibrating reeds threw the current into vibration and two series of electrical waves of equal force were transmitted to the receiver, and corresponded to air-waves of the same pitch. When the reeds were vibrating exactly in unison the sound at the receiver would be very loud, because the two

sets of electrical waves which were transposed into sound-waves at the receiver co-operated. But when one had gained half a vibration, as it did in about five minutes, there was perfect silence, because one set of electrical waves just fitted into the intervals of the other set and produced a smooth flow of current.

The facts brought out in this chapter show how beautifully the laws of nature are adapted to the service and comfort of man. Sounds that have a tendency to prolong themselves are made pleasurable to our senses, and those that are disagreeable are killed as soon as possible after they are born, by a law of their own operation.

CHAPTER XII.

SOUND-LANGUAGE.

By sound-language we mean such sounds as convey a specific meaning, but are not articulate. Articulate speech is an assembling of words with arbitrary meanings and used to convey ideas from one person to another. These meanings have no relation necessarily to the sounds of the words. In fact, many words having the same sounds have different meanings in different languages. Different races of people, shut up by themselves, have developed different artificial languages along lines having definite trends that are the result of a fixed condition of things for a long period of time. These human articulate languages —and that of some birds—are all artificial. But there is a natural language, common to all races and peoples and to most of the lower animals, that conveys a meaning, though not in all cases so definitely, or with such fine shading, as articulate language, although in many instances it is more powerful in its effects. This sound-language takes advantage of a fundamental law, laid down in a previous

chapter, that determines the quality of all sounds, namely, the relation that the overtones sustain to the fundamental tone in the matter of number, amplitude, etc.

For example, if a certain voice, when it expresses grief, contains 1,000 overtones related in a certain way, a voice expressing anger may have 2,000 related in a different way. I do not mean to say that these numbers do express the difference, but only that there is a difference in numbers and relations in the two cases between the overtones and the fundamental tone. The same fundamental tone may be used in both cases, but there will be a vast difference in the number and relation of the overtones.

Who has not heard the cry of a mother-bird —when it has said to you plainly, "Help! help! Somebody or something is disturbing my nest!" You instantly recognize the voice as one of distress, and although you do not see you know that it is a bird in distress, and if you are a kind-hearted person you will run to see if you cannot relieve it. Perhaps a few minutes later you hear the glad song of the same mother, telling you that all is well with the bird and that she is happy.

Who has not, when sitting by his fireside on a dark night, listened to the howling and moaning, the sobbing and sighing of the wind, and the patter of the rain, and was not told

in a voice more expressive than articulate speech that a storm was raging outside? There is a sense of sadness that comes with the moaning and sighing of the wind that differs from other sounds of nature. The waves of the sea as they dash against the rocks and break and fall over and through each other, tell us a story of great power, accompanied by a go-as-you-please, don't-care, jolly sort of feeling.

"The sea is a jovial comrade,
He laughs wherever he goes;
His merriment shines in the dimpling lines
That wrinkle his hale repose.
He lays himself down at the feet of the sun,
And shakes all over with glee,
And the broad-backed billows fall faint on the shore
In the mirth of the mighty sea.

But the wind is sad and restless,
And cursed with an inward pain;
You may hark as you will by valley or hill,
And you hear him still complain.
He wails on the barren mountains,
And shrieks on the wintry sea;
He sobs in the cedar and moans in the pine,
And shudders all over the aspen-tree."

It is said that even the mosquito is equipped with a sort of horn-like process, called the Antennæ, that is movable and vibrates whenever a tone in sympathy with its natural rate of vibration is sounded in his presence, and it is further asserted that his

mate only possesses the magic instrument that will produce the proper tone. We do not vouch for the truth of the foregoing, but we do know that the mosquito is a jolly fellow, for he sings as he goes to his meals.

Mrs. A. and Mrs. B. are visiting in the parlor. Their babies are asleep in a room upstairs. Suddenly a complicated air-motion comes shivering down the stairway which gives Mrs. A. a start, while Mrs. B. remains quiet. The former exclaims, "Oh, my baby!" and runs to him. Why did Mrs. A. start and not Mrs. B.? Because they both knew by the quality of voice which baby it was. Directly the babes are both awake and are playing happily together. The mothers hear them and know they are happy. Hark! There is another cry, and Mrs. B. runs. She knows that it is not only her child, but that the child is in pain. It has been hurt. The child told its mother in a voice that was unmistakable that it was in pain. If the child had been a recently imported Hottentot he would have told the same story in the same way, under the same circumstances. This same natural method is resorted to by the child to tell its mother of grief, hunger or fright, and of the presence of any of the other emotions.

All the multitudinous sounds of nature have a meaning. The humming of the insect, the cry of the child, the song of the birds, the

moaning of the winds, and the dashing of the waves, all tell a story of their own. If a man who nad never seen the Niagara Falls should be blindfolded and taken there without knowing where he was to be taken, and then should be asked where he was, he would say: "I do not know the name of the place, but I am near a mighty waterfall." The "voice of many waters" would speak to him in thunder tones that could not be mistaken. There is a poetic power in this sound-language that never comes with articulate speech, because articulate words convey concrete ideas that rob the language of much that would otherwise be poetic. Natural sound-voices stimulate the imagination far more intensely than the most poetically arranged articulate words.

CHAPTER XIII.

HEAT AND MATTER.

We now come to a subject that is of paramount importance to all kinds of life. Men can and do exist without being able to hear sound or see light, and consequently are without the aid of articulate speech, but it would be impossible to even exist without heat. A life insensible to sound or light and the consequent absence of the power to communicate through the medium of speech is only an animal existence with a very limited intellectual life, such as can be had through the senses of taste, touch, and smell. Heat, like light and sound, has been the subject of much philosophical speculation in the centuries past, but like the advances in electrical and chemical science, which are very closely related to heat, great strides have been made in getting correct conceptions of its nature in the last twenty-five or fifty years.

At one time heat was supposed to be a material—a sort of imponderable fluid that had the power to penetrate bodies under some circumstances, and warm them; something

that poured into you, and when you were full of this fluid you had the sensation of heat, but when it poured out again you were cold. The same sort of material theory prevailed in regard to light, sound, and electricity. For instance, when a bell was struck it was supposed that a very subtle material was knocked out of it and it flew in every direction like so many projectiles. They failed to tell us why the bell did not weigh less after it had been struck than before, and why after a century of ringing the sound did not diminish. It was also supposed that light was a material emanation from the source of light; that the sun was throwing off luminous matter constantly, and that a candle or lamp did the same thing. Electricity was also classed as a fluid. Some thought it was composed of one and some of two fluids, a positive and a negative. Occasionally nowadays we find some one adhering to the old notions in some of their aspects, but in the minds of almost all thinking people the material theory is no longer tenable. It has been supplanted by the mechanical or dynamic theory which applies to sound, light, heat, electricity, etc. The mechanical theory accounts for all the phenomena of sound, heat, light, and electricity, as a form or mode of Motion.

There are two kinds of motion known to physics; one is called mechanical motion, or

motion of a mass of material as a whole, and the other is called molecular motion, which is a motion of the ultimate particles of which the mass is made up. The term molecular is here used synonymously with atomic. Heat is supposed to be atomic motion; and in this connection is called thermic (i.e., heat) motion.

In order to make our meaning clear let us spend a little time in discussing the constitution of matter. There are between sixty and seventy original or ultimate elements in the material universe. All other substances, and their name is legion, are either compounds or chemical combinations of these sixty or more elementary substances. When elements mix without change in their molecular structure they are called compounds. But when two or more elements combine chemically, a new substance is formed; however, it can be resolved back into its original elements by processes well known to the chemist. The smallest particle of an elementary substance is called an atom, and the smallest particle of a substance made from two or more elementary substances, chemically combined, is called a molecule. (See Vol. I.) For instance, oxygen and hydrogen are both elementary substances. Two atoms of hydrogen and one of oxygen combine to make one molecule of water, the molecule being the smallest particle of water

as such. When these three atoms that form a molecule of water are wrenched apart again, the water molecule is destroyed, and what is left is simply two atoms of hydrogen and one of oxygen. If now the gases in this proportion are ignited by heat an explosion takes place and the result is water again.

Sir William Thomson (now Lord Kelvin) made a computation of the number of molecules in a cubic inch of solid matter, and his estimate is that there are 100,000 million million million. The figures are so large that they really convey no idea except that of a large number. A little better conception is had in this comparison which he gives—that is, if a drop of water were magnified to the size of the earth and its molecules were magnified in the same proportion they would not be smaller than shot or larger than cricket balls. These dimensions, small as they seem, are after all just as real as though they appeared to the natural eye and not simply to the eye of the imagination.

It may be said that there is another theory of matter, but the statement of it is so vague that it would only confuse the reader. In short, it assumes that there is but one elemental substance (called ether) and one energy, and that when we speak of different kinds of matter we only mean different affections or states of matter brought about by the

play of forces upon the one elemental substance. Whether or not this be true makes no difference with the facts of natural law, and as the mechanical or dynamic theory explains all the facts of chemistry and physics we will proceed on that basis. At best the new theory, if true, is only an attempt to carry the present theory farther back. Another thing must be kept in mind: Supporters of the dynamic theory (motion theory) assume that all space not occupied by matter is filled with a subtle and infinitely elastic substance called luminiferous ether. (The one elemental substance above referred to.) It is called luminiferous because it is the medium through which light is transmitted. This fluid is so refined that no material substance will resist it. It will pass through any known form of material. In fact, it surrounds all the atoms or finest particles of matter. In other words, the smallest particles of matter float in this subtle fluid. The molecules of matter do not touch each other. At least there is room for the play of the molecules, as we shall see further along. There is not only room for the play of the molecules, but also for the play of the atoms of which the molecules are made up.

In our first chapter on sound it is stated that all the avenues to the brain are traversed by some form of motion. In other words, all sensation caused by an effect from the world

without comes through the medium of motion in some form. Heat produces a sensation and is therefore a mode of motion.

The ether that has been spoken of is so refined that no vessel could be made that would hold it. It is like the universal solvent that a man is fabled to have invented. When he got it made, every vessel he put it into was dissolved, and he had to abandon what promised to be a great enterprise for want of suitable vessels to hold it.

Matter is found in three conditions—solids, fluids, and gases. Solids and fluids are held together by an attraction similar to the attraction of gravitation, called the attraction of cohesion. The molecules of solids cohere so closely that the mass of matter as a whole is held in a rigid condition, some substances being held more rigidly than others. Fluids are held so loosely that the molecules, while they cohere, can move freely around each other, while the molcules of gases are so far apart that the attraction of cohesion is entirely overcome and they tend to fly off into space. There is a repulsion between the molecules of matter, so that when they are freed from the attraction of cohesion they tend to fly off in every direction, and one of these repulsive forces is heat. As has been stated, heat is a mode of motion. It is a motion of the individual particles of a solid, however

rigid it may be, that gives it the phenomenon of heat. The same is true of liquids and gases. Heat is atomic motion as distinguished from mechanical or mass motion. It is a motion of the atoms of which molecules are formed.

Some of you have lived, or do live, in the country, and have seen a swarm of bees come out of a hive. They follow their queen until she lights; often it is on the limb of a tree. They pile onto each other till they have formed a mass as large as your head or larger. Now if we should swing the limb on which the bees have lighted, the mass of bees will move as a whole, and this we call mass or mechanical motion. At the same time if you could see every individual bee you would see that each one was moving independently of the whole mass. They are the units of which the mass is made up. This individual motion of the unit may represent what is called molecular or atomic motion, which, in one of its forms, at least, is heat.

The above illustration would appeal to the natural eye; but now come with me into the realm of the unseen, which is as real as the visible things, and use your imagination, and conceive of a mass of matter one cubic inch in size made up of small particles called molecules, and that the number of these molecules in a cubic inch is 100,000 million million millions, and each one of these molecular units

has an independent motion—like the bee in the mass of bees—and you have the idea which I wish to convey. If we heat a body we increase the amplitude and rapidity of the motion of its ultimate particles, and therefore each particle must have more room in which to vibrate. We should expect in this case that the whole mass would be increased in size in order to give the room required for their increased molecular activity, and this we find to be the case, and thus we have in this fact the phenomenon of expansion that every one is familiar with. If we apply heat to a piece of metal it swells or expands. If we keep on increasing the heat it keeps on expanding till the attraction of cohesion is partly overcome, and the molecules can glide around each other, when we have the phenomenon of liquefaction, and we say the metal has melted. Some metals melt at a much lower heat than others, due to the fact that cohesion is less in some than in others.

If we apply heat to a piece of ice, which is solidified water, the ice melts and we have water in the liquid state. If we keep on heating the water at a certain temperature it bursts into a vapor we call steam. The molecular activity becomes so great that the attraction of cohesion is no longer able to hold the particles together, and they fly off into space. If we pass an electric current through a body

of water-molecules they are still further separated into fixed gases called oxygen and hydrogen. As before stated, these gases in the proportion of two atoms of hydrogen to one of oxygen unite again to form water, when heat is applied sufficient to ignite them.

If heat is motion, you ask what is cold? Is there any such thing as an absolute zero of cold? There may be, but it does not come within our experience. Heat and cold are relative terms, and the two are combined in the word temperature. If the temperature goes down to 80 degrees below zero in the Klondike, as it is said to do, it may go lower at the North Pole, and doubtless does. In that case it will be warmer in the Klondike than at the North Pole. If it be true, as we have seen, that increased heat means increased motion, it follows that decreased heat means decreased motion, and decreased motion is cooling while increased motion is heating. Thus there must be some heat so long as there is any motion. I only refer to this phase of the subject for the purpose of giving you a clearer idea of what heat means.

Gases expand much more readily and in a wider range than liquids or solids. As children, doubtless, many of us can remember seeing a bladder inflated and then laid on the hearth before a fire when it expanded under the action of heat till it would burst with a

loud report. In this case, the molecules of the gases that go to make up atmospheric air (chiefly oxygen and nitrogen) are thrown into more and more violent vibration, thus making it necessary for more room to accommodate this play of the particles of air; and when it meets with resistance it bombards that resistance with millions of little projectiles till it has to give way if not strong enough.

CHAPTER XIV.

EXPANSION.

Expansion under heat is able to produce enormous pressure. The iron or steel rails laid down on the ties of a railroad bed have to be separated at the joints where they abut, so as to allow for the increased length when they expand during a hot day. A story was told me as coming from a locomotive engineer who was running a train across the western plains one very hot day, that illustrates the wonderful power of expansion. He said that the track for a long distance in front of him suddenly picked itself up, ties and all, from the road-bed and laid the whole thing over in the ditch without disconnecting the rails or detaching them from the ties. The day being very hot, the rails had lengthened till all the spaces between the ends of the rails had closed up and something had to give, for the expansive force of solids, although short, is irresistible. The jar of the train as it approached (the rails being under great strain) was just enough to loosen the ties from the road-bed, when the track moved upward and outward

in the arc of a circle, till there was room to accommodate the increased length of the rails due to expansion.

Every day when the sun shines the top of Bunker Hill monument is thrown out of plumb several inches by the power of expansion. The same is true of any tower or shaft constructed in the same way. The side that the sun's rays fall upon is expanded, while the opposite remains practically the same. All the molecules on the sunny side are thrown into greater activity, and as we have seen require more space in which to move. This causes the column to bend away from the sun in the form of a curve. A curious exhibition of the power of expansion is related by Tyndall as taking place on the roof of the Bristol Cathedral. He says: "The [roof of the] choir of the Bristol Cathedral was covered with sheet-lead, the length of the covering being sixty feet, and its depth nineteen feet four inches. It had been laid on in the year 1851, and two years afterward it had moved bodily for a distance of eighteen inches. The descent had been continually going on from the time the lead had been laid, and an attempt made to stop it by driving nails into the rafters had failed, for the force with which the lead descended was sufficient to draw out the nails. The roof was not a steep one, and the lead would have rested there forever without slid-

ing down by gravity. What then was the cause of the descent? Simply this: the lead was exposed to the varying temperatures of day and night. During the day the heat imparted to it caused it to expand. Had it lain upon a horizontal surface it would have expanded equally all round, but as it lay on an inclined surface it expanded more freely downward than upward. When, on the contrary, the lead contracted at night, its upper edge was drawn more easily downward than its lower edge upward. Its motion was therefore exactly that of a common earthworm; it pushed its lower edge forward during the day and drew its upper edge after it during the night, and thus by degrees it crawled through a space of eighteen inches in two years."

A much more wonderful exhibition of the expansive force of heat is found in the play of the geysers of our own Yellowstone Park. In what is called the Upper Geyser Basin there are hundreds, yes, thousands, of hot springs in all phases of activity, from the boiling water to the spouting geyser, often rising hundreds of feet into the air. Some years ago I visited the park and spent some time studying the wonderful phenomena of that most interesting region, and I venture to say that to any lover of the marvelous in nature there is no spot in the wide world where there

is so much of intense interest as there is to be found within the area of a few hundred acres in the Upper Geyser Basin of Yellowstone Park. It would be difficult to explain the operation of some of these geysers, for they are very complicated. Often one great geyser will be connected with a great many smaller ones, together with boiling springs, all of which play some part in the grand exhibitions that periodically occur. The phenomenon of a single geyser such as "Old Faithful," that plays so regularly that one may set his watch by it, is not difficult to explain.

Let us construct in our imaginations an artificial geyser. We must premise, however, a few remarks regarding the boiling-point of water. Water bursts into steam at 212 degrees Fahrenheit in an open vessel at sea-level, but at the top of Mont Blanc it boils at 185 degrees Fahrenheit. The boiling-point of a fluid is always that point where the tension of the vapor is equal to the pressure of the atmosphere. At sea-level the atmospheric pressure is fifteen pounds to the square inch, and so fifteen pounds to the square inch is the unit of pressure for gases, and is called an "atmosphere." Any pressure less than fifteen pounds is less than an atmosphere. It will be seen from the above that water boils at less than an atmosphere on top of Mont Blanc.

Fluids will boil from the heat of the hand

if the pressure is sufficiently reduced. On the other hand, if the pressure is more than one atmosphere, water will not boil at 212 degrees, but will require a higher temperature. If we put water into a strong bottle with a large mouth and boil it over a spirit-lamp at sea-level it will boil at 212 degrees. Now cork the bottle and it will soon stop boiling on account of the additional pressure caused by the steam in the space above the water. The pressure now is more than one atmosphere. But if the heat is kept up it will reach a point where the tension of the vapor will overcome the resistance of the cork and the cork will fly out. What takes place? The pressure on the water immediately drops to one atmosphere. The water in the bottle is heated much above the boiling-point at one atmosphere pressure, therefore as soon as the pressure is taken off, by the cork flying out, the water all bursts suddenly into steam.

Let us take a tube any length—say six feet long and one inch in diameter—close it at the bottom end and surround it with a basin at the top and fill it with water. Now apply heat at the bottom of the tube sufficient to boil the water. It will require more than 212 degrees to boil it at the bottom on account of the pressure of the column of water above. But finally it does begin to form steam at the bottom. This lifts the column of water so

that some of it runs into the basin. Immediately this takes place the pressure on the overheated water at the bottom is taken off enough to allow it all to burst into steam, when the whole column of water above is thrown into the air. This cools the water, and as it has been caught in the basin it runs back into the tube, when in a few minutes the same operation is repeated. The above will illustrate the fundamental law that is active in the play of a natural geyser. Geysers are found where there are heat-vents reaching down into the interior of the earth. These vents occur where the crust of the earth has been broken, as it is on mountain ranges. They are the ending up of what was once a volcanic crater. It is necessary for these heat-vents to be located where water can run into them in order to produce geyser action.

A natural geyser in most cases forms itself. It starts with a boiling spring, the hot water being loaded with silica, or, as it is called, geyserite. This in most cases is pure white and is deposited on the sides and top around the spring and gradually builds up, sometimes to a great height, forming a tube. When the tube gets sufficiently long and the heat at the right distance below is sufficiently great it begins to flow intermittently; the longer the tube —the thermal conditions being the same—the longer the time will be between the eruptions.

of the geyser. Of the principal ones I saw in the Upper Geyser Basin of Yellowstone Park, the "Sawmill" played every few minutes; "Old Faithful," every hour; the "Grand" and "Splendid," about every twenty-six hours; the "Giant," once in four days, and the "Giantess," once in fourteen days.

I was so fortunate as to see all of these and many more in operation. It was a wonderful illustration of the effect of motion upon emotion. No two of them produced the same effect upon the beholder. "Old Faithful" was majestically grand. It gave one a sense of great power exerted with wonderful grandeur and dignity. The "Giantess" was very erratic in her play (and this is no reflection upon her sex), throwing the water first one way and then another—pausing a moment and then starting up again. And this was kept up for many hours, while most of the geysers stop playing in a few minutes. But the "Giantess" is only the chief one of a system of smaller geysers that are connected in some mysterious way with the mother of them all.

About 200 feet from the "Giantess" is a geyser called the "Beehive," that always plays a certain number of hours (I think eight) after the "Giantess" begins. One-half hour before the "Beehive" plays there is a little jet—two or three inches in diameter—that starts up close beside it, and this is called the indi-

cator. The "Beehive" is a curious formation. It has a nozzle something like a fire-hose, only about three feet in diameter and stands up several feet above the surface. When it plays it does so with terrific force. It throws a round jet 100 or more feet into the air the full size of the nozzle. The roar is like thunder, and can be heard for miles. Any sized stone that is thrown into the stream is carried upward with great force. The effect of this geyser is to almost terrify the beholder—it conveys such a sense of awful power.

But the geyser that produced the greatest excitement and enthusiasm of all was called the "Grand," which played once in twenty-six hours. It will be impossible to give an adequate word-picture of the play of this wonderfully beautiful geyser. When I saw it in action it was late in the afternoon, and, standing between the sun and the geyser, with my back to the former, I had the advantage of the reflected light, which is very bright in that high altitude. Close by the side of the geyser is a steam blow-hole about six inches in diameter, and all about are a number of boiling springs that are connected with the geyser. Just before the play begins all these springs are in great agitation in sympathy with the coming event. As a final preliminary, this steam blow-hole starts up, giving a blast of terrific power. I once witnessed the coming

of the Sultan of Turkey through the palace gates, where he found himself surrounded by 10,000 soldiers, who blew trumpets and sent up shouts that were intended to be very impressive, but this scene paled in impressiveness when compared with nature's announcement of one of her grandest displays. Immediately the steam trumpet made the announcement, the water in the top basin of the great geyser heaved several times as if unable to make a start, and then lifted itself up bodily for more than 100 feet into the air, when there began the most beautifully sublime and at the same time the most exciting spectacle I ever witnessed before or ever expect to again. It assumed the shape of a beautifully formed evergreen tree whose branches cover the trunk down to the ground, the tips of which are loaded with cones set with purest diamonds. These cones shot out from the center on moving stems and burst into brilliancy at the limit of the tree-like form, producing an effect something like that of a rocket when it first bursts in the air, and before it has fully spread. Imagine thousands of these jets moving in all directions and bursting into beautiful colors, now vanishing and now others taking their places, till one is excited to the highest pitch by this wonderful exhibition of color, form, and motion. All the time nature's great steam foghorn is sounding its thunderous note beside

the geyser as if sympathizing with this mighty effort of pent-up energy.

After keeping up this wonderful display for fifteen minutes it suddenly stops—all but the steam jet, which seems as vigorous as ever—and the water rapidly recedes down the tube of the geyser till out of sight. In a few seconds the water is seen quietly but rapidly coming to the top, and when it reaches there it suddenly bursts into full form and height for one short moment and recedes as before. It comes back and recedes seven times, and at each coming it makes the same burst, until at the seventh pulsation the steam-jet suddenly stops, as much as to say, "Gentlemen, the show is over." All the numerous springs that are connected with this geyser are now found to be empty.

Such are some of the wonderful exhibitions caused by the expansive power of heat upon water.

CHAPTER XV.

TERRESTRIAL HEAT.

After reading the last chapter on geysers one will naturally inquire: "Whence the heat that is able to produce these wonderful displays?" Undoubtedly it comes from deep down in the earth. There is every reason for supposing that at one time this earth was a molten mass of matter, which for millions of years has been gradually cooling off until a thick crust has been formed; so thick that vegetation and animal life has to depend upon the heat of the sun. At one period of the earth's history, called by geologists the carboniferous, or coal-bearing, age, vegetation was forced by the internal heat forming a hotbed, as it were, that caused a wonderfully rank growth of all sorts of tropical plants and trees. This vegetation grew and fell down for ages, and laid the foundations for our coal-beds and oil-fields, as well as being the occasion of the great reservoirs of natural gas. The fact that these coal-beds are found in the cold regions of the north gives color to the theory of the carboniferous age. When the earth had cooled

sufficiently the aqueous vapor and other matter precipitated (but not until a crust of sufficient thickness had been formed), stratified rocks were laid down in the hot water, and this precipitation probably went on for ages before the "dry land appeared," and when it did appear it came about in this way: As the molten mass cooled it first formed a crust; it kept on cooling and made a void by shrinkage between the crust and the molten mass. When this had gone on to a certain point and the crust was no longer able to support itself, it fell in; and as the earth was round the crust had to wrinkle; hence our mountain ranges formed at different periods of the earth's history.*

The great rocky range extending from Alaska on the north to Patagonia on the south of our North and South American continents, was undoubtedly once a vast volcano throughout the whole extent—or practically so, and why? Because when the earth's crust fell toward the center by the attraction of gravitation it broke at these wrinkles (the mountains) and thus made a vent through the crust to the molten mass in the center. What wonderful convulsions there must have been in those days! What earthquakes! What an exhibition when the water and the heat first came into contact! Not only mountains were

* See Vol. I. "World-Building."

formed, but also valleys or great depressions. Into these depressions the water ran, and hence our oceans.

Speaking of earthquakes, they are caused in most cases by the occasional settling that occurs from time to time after the internal pressure has been relieved by a volcanic eruption; most often in regions near where the crust is weakest—namely, the mountains. The rifts in the rocks make a vent for nature's great furnace.

Gradually the earth has cooled until only a few of these vents are active volcanoes, and still fewer appear as geysers, and these undoubtedly will disappear in time. The water from the surface runs down into these heat-vents, which come from the core of the earth, and is thus heated, and through the complicated structure of these heat-passages and the peculiar system of tubes formed by hot water and silica we have these multiphased phenomena of geyser action. It is found in boring for artesian wells that the temperature rises one degree for every thirty meters. This fact would go to show that it would get very hot at that rate at some point far enough down.

We bore for water, we bore for oil, and we bore for gas. Who knows but that when fuel becomes scarce we shall bore for heat and carry it in protected pipes to our dwellings and fac-

tories? I would not care to be near by when the well-digger should first shove his drill through the crust. However, it would be hot enough for most domestic purposes long before he reached that depth.

There are different theories as to the cause of the earth's heat. Some have supposed that it was caused by chemical action. Others that at some time two planets have collided and that the impact caused both to melt with "fervent heat," when they ran together into one body and assumed the spherical shape. This is not likely, for such a collision would arrest their motion, in which case they would both, most likely, have fallen into the sun, as there would have been no power left to overcome the attraction of that great luminary. A more probable theory is the one called the nebular theory. This theory assumes that at one time all the cosmical matter now composing the whole solar system was in a finely divided state and filled, like a gas, the whole space occupied by our present solar system, as one body. By the law of attraction these particles of matter came closer and closer together—all pushing toward the center of the mass. This movement, or contraction, caused a rotary motion, slow at first, but increasing as it contracted. At a certain point heat developed, and, after a sufficient heat, light. When it had condensed to a sufficient extent to approach

fluidity, rings like those of Saturn were thrown off by centrifugal force. When these rings cooled sufficiently they broke and rolled up into a ball, thus rotating on their own axes as well as around the mother mass. This process has kept up till all the planets have been thrown off from time to time, and what is left of the core is the sun itself. By this theory the earth and all the planets are daughters of the sun, just as all of us are sons and daughters of the sun, as we have seen from reading the chapters on world-building, in Vol. I.

CHAPTER XVI.

GENERATION OF HEAT.

Heat is an energy, and as such can do work. If we wind up a weight to a given height and let it fall, the weight will be hotter, the pulleys will be hotter, the air will be hotter, and the earth on which it falls will be hotter. If all the heat generated by the winding and the fall could be gathered up and put into mechanical energy it would just be sufficient to raise the weight again to the height from which it fell. (See the chapter on Energy.)

The sudden arrest of mechanical motion has been converted into molecular or heat motion, for energy is never lost; it is represented somewhere. To-day it may be heat, to-morrow mechanical work, next day electricity, and the next it may return to heat again, or it may be stored away as potential energy by the growth of wood and reappear as heat at some future time when it is burned. Energy is as indestructible as matter. I may burn a cord of wood to-day and what appears to be left of it is a small pile of ashes. It has not been destroyed; all that is not represented by the ashes is floating in the air as gases and the

sunbeam will gather it up and put it back into wood again. But, you say, the wood is gone; true, it no longer exists as wood, but the elements of which the wood was made still exist, and may be made into wood again through the agency of nature's great laboratory.

If we fire a bullet from a gun, the bullet heats itself and the air through which it passes, and if it strikes a solid substance so that the motion is suddenly arrested, the bullet and the target are both heated by the impact. Bullets sometimes melt from the sudden conversion of mechanical motion into heat motion. If all the heat created by the bullet were saved and put into the right shape as stored energy, it would fire the bullet again with the same force. Take a small iron rod and lay it on an anvil and strike it with a hammer a few dexterous blows, and it may in this way be heated to redness. The mechanical energy put into the hammer-blows is now represented by the heat of the rod, the anvil, and the hammer, and a small amount in the air created by friction.

Helmholtz has made an estimate of the amount of heat that would be developed if the motion of the earth could be suddenly arrested. He figures that there would be heat enough not only to melt the whole of the earth, but to resolve a large part of it into the gaseous state.

The above are illustrations of the production of heat, or molecular motion ("molecular" and "atomic" are used synonymously when speaking of heat), by the sudden arrest of mechanical motion. Heat is also developed by friction. If we rub two sticks of dry wood together and rub long and hard enough we can produce heat to the point of ignition. If we take a tube and close one end, then fill it with water, and after corking it tightly revolve it rapidly in a lathe, while two pieces of wood are clamped around it so as to produce a friction, the water will soon heat to the point of generating steam, and blow the cork out. Suppose we should fill the tube with shot instead, and revolve it. If we apply no friction the shot will be carried around quietly, but if we put our clamp on and produce friction the shot in the tube will be agitated and have a tremulous motion. Now conceive of the tube again, and the water within it being shot, so small that 100,000 million million million could occupy the space of one cubic inch and simply held together by an attraction that can be overcome, and you can see how these very small particles could be thrown into a vibratory motion. This motion is heat.

A wonderfully striking effect of friction is seen in what are called shooting stars or meteors. (See Vol. I.) Floating in space are untold millions of fragments of planetary mat-

ter moving in great schools like fish in the ocean, each collection having its own orbit of motion like the planets. They are not visible to the eye unless they stray within the limits of our atmosphere, which they often do at certain times in the year. The atmosphere does not extend very high up from the earth's surface. Only a few miles at most. These vagrant collections of meteoric matter are moving at a very high rate of speed, and this, added to the movement of the air, which revolves with the earth, causes such a friction of the meteoric matter with the air as to heat it to a glowing white heat, causing it to disintegrate till it is entirely reduced to dust, which in time precipitates to the earth or floats about in the air. The sudden heating up of these meteoric masses makes them visible to us, and as they rush through the air, gradually consuming with the intense heat, we call them "shooting stars." Sometimes it happens that the substance is too large to be consumed before is strikes the earth.

This meteoric dust, as I have said, at least some of it, descends to the earth and therefore the earth is gradually but imperceptibly increasing in size by accretion.

If a train of cars could be run at a high enough rate of speed it would take fire and burn up, the same as a meteorite. Judging by our own experience, in riding against the

wind on a cold day, we should conclude that the faster one goes the colder he gets. This is true up to a certain limit of speed. The air-friction is not great till a high speed is reached. When one is standing, and there is no wind, a shell of warm air soon surrounds the body and protects it from the cold, but as soon as we move we get away from this warm shell into the colder air. Thus it is that the heat of the body is lowered more rapidly when moving. But if the velocity of the movement should reach that of the meteor we should meet the fate of the meteor.

Another mode of generating heat is by combustion. This mode is the most common of all for domestic and manufacturing purposes, both for heat and light. In this day of electricity modes of lighting, and in some degree those of heating, are changing. We now have for domestic purposes light, and to a limited extent heat, produced by electricity. The direct application of heat and light from this source is not by combustion. When we turn a current of electricity through the carbon filament of our electric lamp (incandescent) there is no combustion. There could not be because there is no oxygen inside the globe; it is a vacuum. The electric current simply heats the carbon filament to whiteness so that it emits light. This will be fully explained under the head of Light. If we should let in

the least quantity of air the filament would instantly burn up—that is, combustion would take place. The atoms of oxygen would clash with the particles of carbon and reduce it to carbon dioxide.

It will be seen by this that we can have heat without combustion: but we cannot have combustion without heat. The electric light depends primarily upon combustion in most cases, although it is not a necessity. We could use a galvanic battery and get our current by chemical action, but this is a sort of combustion. Somewhere there is a furnace—a steam-boiler, an engine, and a dynamo that generate the electricity. In the furnace is used some kind of fuel. In common life oxygen is almost universally the supporter of combustion because it exists in the atmosphere. If we take a diamond, which is pure carbon, and heat it to redness and then plunge it into a vessel containing pure oxygen, it will turn to a white heat and burn up. The carbon must be heated to a point where the oxygen will unite with it. All combustibles have to be heated before the oxygen will unite with them to burn. This is a wise provision, otherwise we should be in constant danger of being burned up, for we are floating, as it were, in a sea of oxygen, and our very clothes as well as our bodies will burn if the conditions are right.

Let us now get back to the electric-light

plant, and build a fire under the boilers, and see what happens. We strike a match. The match is capped by material that unites with oxygen at a low heat, so that the heat generated by moderate friction is sufficient to cause combustion. We apply the match to the kindling and immediately the atoms of oxygen clash with the hydrocarbons of the fuel. Combustion and flame result. The heat communicates to the surrounding fuel and more oxygen pours in, and this goes on till the whole mass is ignited. During the process of combustion intense heat is generated, caused by the molecular activity of the atoms of matter when they unite chemically. This motion is imparted to the metal of the boiler, and thence to the water within. When a certain stage of motion of the molecules of the water is reached they are rent asunder by the violent motion and they burst into steam, which, expanding, tries to get out. This produces pressure. The pressure is applied to a steam-engine that causes mechanical motion; the wheels turn and the dynamo is brought into action.

If we take a piece of soft iron long enough to reach from one pole of a magnet to the other (either electro or permanent magnet) and wind a coil of insulated wire around it, connecting the ends together, then place the two ends of the iron near to or in contact with

the poles of the magnet and jerk it away, a momentary impulse of electricity will flow through the wire both at the moment of approach to the magnet and when it is taken away: thus mechanical is converted into electro-atomic motion. This is the underlying principle of the dynamo.

Here mechanical motion is converted into a peculiar form of molecular motion that we call electricity instead of heat. This new motion flies through the wire (which has been provided for conducting it) at lightning speed, and when it reaches the lamp it meets with a resistance in the carbon filament. Now another change takes place. The peculiar motion of the molecules of the conducting wire can no longer be kept up as electricity, so it is largely converted into heat, and heat made sufficiently intense results in light. It starts in heat and ends in heat. First energy in the form of heat—then mechanical energy — then electrical — and finally heat again. (The nature of the electrical motion is not well understood. It will be discussed under Electricity, in Volume III.)

The operation of combustion in a common candle is as follows: The wick, which acts chiefly as a carrier of the fuel, is lighted; the tallow is melted and rises by capillary attraction to the point where combustion takes place. The tallow is chiefly a hydrocarbon, a

combination of hydrogen and carbon. By the union of the oxygen of the air and hydrogen—which forms water—free carbon particles are released and the first effect is to heat these particles to a white heat. The lighting quality of a candle, lamp, or gas-jet is the incandescence of these carbon particles; but they are short-lived—for immediately the carbon particle is set free from the hydrogen, the oxygen of the air attacks it and it is consumed before it travels an inch, if the air can get at it freely. If not, it goes off as smoke, which is made up of free (unconsumed) particles of carbon. Another result of the burning of a flame is the formation of water—one part of oxygen unites with two of hydrogen, and the result of the combination is water. When you first light a lamp—especially a bicycle-lamp—you will notice moisture collect on the inside of the glass—chimney or lens, as the case may be. The glass is cold at the start, so that the water-vapor condenses, but in a few minutes the glass is heated and the water-vapor passes off with the heat as a transparent vapor to be condensed into water at some future time.

A burning flame is made up of an infinite number of explosions so light as to scarcely be heard. The explosion occurs when the oxygen unites with the hydrogen to form water. If a large body is ignited all at once it explodes with terrific force. I remember

vividly an experience in my student days with a hydrogen-lamp that I attempted to make. I put a small tube through a cork and fitted it to a quart bottle. I then put some bits of zinc into the bottle and poured on them a solution of sulphuric acid and water. Immediately hydrogen gas began to form, and if I had waited till all the air had been forced out of the bottle my lamp would have been a success, for pure hydrogen burns from a jet with a steady flame. In my enthusiasm I lighted it prematurely, and the result was a hole in the ceiling, and a scared landlady, coupled with an admonition not to try it again.

CHAPTER XVII.

DIFFUSION OF HEAT.

Heat tends to diffuse itself in three different ways, namely, by conduction, convection, and radiation. If we heat a metal rod by putting one end of it into the fire, it does not immediately heat the whole length, but travels slowly along the rod. The molecules that are in immediate contact with the fire have their atoms excited to intense motion; these communicate their motion to the next layer, and so on, from layer to layer, until the rod is more or less heated the whole length. This process of heat-diffusion is called conduction. Some substances conduct heat much more readily than others. A pure silver teaspoon is a nice thing to have, but it is the most inconvenient of all spoons to use in hot tea or coffee. Silver, gold, and copper are all good conductors of heat, as well as of electricity. If we call the conducting capacity of silver 100, copper will be 74, gold 53, brass 24, tin 15, iron 12, and lead 9. These metals also conduct electricity in about the same relation. The metals or other substances whose molecules are most readily ex-

cited are the best conductors of both heat and electricity.

This fact seems to establish a close relationship between heat and electricity, as indeed there is; for we shall see that electricity turns to heat the moment it is resisted, and as no conductor is perfect it is resisted to a certain degree at all times, and is, to that degree, developing heat. All conductors of electricity are more or less heated when a current is passed through them. On the other hand, heat will develop electricity under certain conditions. This phenomenon will be discussed when we reach the latter subject.

Let us now consider the diffusion of heat by convection. Convection means the act of conveying; and when it is applied to heat it refers to heated masses of air, gases, or fluids moving in a body from place to place. If we put one end of a copper rod or other metal in the fire and let the other end run into a small chamber, the rod will be heated its whole length by conduction, but the air in the chamber will soon be heated by convection. The air next to the rod, as soon as heated, rises to the top of the chamber, because heated air is lighter than cold; the cold air will drop down and be warmed by the rod and rise again. This process goes on until all the air is warmed alike. Hot-air furnaces in dwellings heat the rooms by convection. And hot-water systems

heat in the same way to a large extent. The Gulf Stream is a vast warm-water system that warms continents instead of rooms in dwellings. The water of the ocean lying under the direct rays of the sun becomes heated and is set in motion, probably by the rotation of the earth, or possibly there is a combination of causes at work. Some have attributed this motion to the effect of the trade-winds, but it is hard to believe that this is the case to any considerable extent. At any rate, currents are set up in different oceans, the most notable of which is called the Gulf Stream, as it apparently has its origin in the Gulf of Mexico; at least it receives a fresh impetus at that point. It follows along the Atlantic coast as far as Wilmington, N. C., and it then crosses the Atlantic, enveloping England, Ireland, and Scotland, thus modifying the climate of the whole of western Europe clear to the North Cape—the land of the midnight sun.

The great harbor of Hammerfest is free from ice all the year round, although opening into the Arctic Ocean. One of the industries of Norway is agriculture, and yet the northern part of Norway is about as far north as the Klondike in Alaska. At the Klondike the temperature goes to 70 or 80 degrees below zero, while at Hammerfest the harbor is open the year round. Such is the effect of nature's mighty warm-water-heating system.

The sun, 90,000,000 of miles away, sends quivers of ether-waves at the rate of about 200,000 miles per second, which are arrested by the waters in the equatorial regions, and here the ether-waves become heat. From there the warmed waters are distributed so as to affect the climate of a large part of the habitable globe. The distribution of heat is by convection on a large scale.

Another of nature's modes of distributing heat by convection is by means of air-currents. Large bodies of heated air rise at the equator and flow each way, north and south, in the higher regions of the atmosphere; that is to say, they would flow north and south if it were not for the earth's motion. This motion changes their direction somewhat. These air-currents flow northerly and southerly for a certain distance and gradually drop down. The cold air at the surface moves toward the equator to supply the place of the heated air. So there is a continual round of air-currents moving in opposite directions on both sides of the equator, and these are called the trade-winds. (See Vol. I.)

Within certain limits, on the ocean, these winds are regular; on land they become broken up owing to the varying conditions of temperature and topography. It is a common notion that the trade-winds are so called because they are an important factor in the

commerce of the world, as sailing vessels can always rely upon these winds in certain latitudes. The original meaning of "trade," however, is a track, trail, course, path; and the name trade is given to these winds because they keep a certain course or path. As the earth—owing to the fact that the plane of its orbit around the sun does not coincide with that of the equator, apparently (not really) has a yearly oscillation each way from the equator as well as a daily revolution on its axis, it follows that the vertical rays of the sun at noon are constantly changing their position. It is found that the position of the trade-winds changes with the oscillation of the earth. This oscillation is between the Tropic of Cancer at the north of the equator and the Tropic of Capricorn at the south. The sun's rays are vertical at the Tropic of Cancer on the 21st of June, at the Tropic of Capricorn on the 21st of December, and at the Equator on the 21st of September and March respectively.

CHAPTER XVIII.

RADIATION OF HEAT.

We have seen in the previous chapter how heat is diffused by conduction and convection, both comparatively slow processes. We now come to another means that plays a very important part in the economy of nature, to wit, radiation. Radiant energy appears under different heads, but all forms are closely related. Light, magnetic lines of force, and radiant heat are all forms of radiant energy, and all travel through space at the same rate, namely, about 188,000 miles per second.

Radiant energy does not require a material substance for a transmitting medium—at least, not material as commonly understood—something that appeals to some one of the five senses. Radiant heat is transmitted through the ether that I have described further back in another chapter. Ether, if it is anything, must be a substance of some kind, but so refined that it permeates the pores of all ordinary material substances, no matter how dense they are. A glass will hold any kind of liquid, although it is full of holes like a

sieve. Those holes are large enough for the ether to pass through, but not large enough for the molecules, or atoms, of matter to pass through. In other words, the glass is water-tight or fluid-tight, but not ether-tight, and as ether in motion is radiant energy, radiant energy can pass through bodies of matter. Light and radiant heat are able to come out through the shell of an incandescent electric-lamp, although the heated film is in a vacuum, —that is, a space absolutely empty of air. Nothing but the ether can get inside of the lamp-bulb. All but a few miles of the distance between us and the sun is what we would call a vacuum, as it has no air, and yet the heat of the sun is able to pierce through, with mighty effect, a distance of over 90,000,000 of miles. Right here let us make a few experiments to show the relation of heat, light, and sound in some of their effects.

Let us take two parabolic reflectors and place them facing each other at some distance apart. If now we place a light in the focus of one reflector, it will be reflected in parallel lines to the other reflector, and thence to the focal point, where a spot of light will appear if a screen is there to receive it. Again, place a watch at the focal point of one reflector and your ear at the other, and you can hear the watch tick very plainly. Now remove the watch and place a spoonful of powder at one

focal point and a ball of metal heated to redness in the other, and immediately the powder will be fired.

These experiments show that sound, light, and radiant heat follow the same law of reflection. If, however, you could perform the same experiment in a vacuum, you would get the same results with light and radiant heat, but you could no longer hear the watch tick. This shows that sound requires air or some material substance to transmit it, which is unnecessary for radiant energy in the form of light and heat. The powder would burn in a vacuum—because there would be sufficient oxygen in the ingredients of which it is composed to support combustion.

The amount of heat radiated by the sun and falling upon a given area of the earth's surface in one hour has been estimated to be equal to the heat arising from the combustion of a layer, over the same area, of the densest coal ten feet thick. At this rate it would require a layer seventeen miles in thickness to be equal to the heat radiated by the sun in one year upon the same area. Of course, if the heat of the sun, for one hour even, should be confined to the surface where it falls, no life, animal or vegetable, could exist. Happily for us means are at hand to take care of it, and render it not only harmless but the greatest boon to all kinds of life. The earth is heated

and this heats the lower stratum of air. Heated air immediately rises, and colder air comes in from the sides to take its place, which in turn is freighted with heat and ascends, so that there is a constant distribution of heat going on by convection through the medium of the air. And thus the temperature at the earth's surface is kept within the range of animal and vegetable life.

The question naturally arises: How long at this rate will "'the lamp hold out to burn"? Well, long enough for you and me and thousands of generations to follow. Within historic times there has been no perceptible diminution of the sun's heat. We find the vine and the olive growing in the same zones as in the times of Abraham. However, if there is no means of compensating for the loss of the sun's heat, in the very nature of things, measured by what we know of the laws of heat upon the surface of the earth, it must gradually diminish in power. Planets, like everything else, have a birth, a growth, a decay, and a death. New planets will take their places that will be fitted, perhaps, for higher forms of life. What is true of individuals is true of races. They have their day; they play their little part, and are gone. Gone, you say? Yes, to the natural eye—as mere living, breathing forms, although to the eye of faith we only change. But here we are treading on the toes

of the theologian. He can stand it, for they have been trodden on before, and will be again.

We build up symmetrical structures of belief that appeal to the intellect, and men live upon them and die by them. These structures are perhaps founded on some dogma that in the march of progress has had accidentally or otherwise a light thrown upon it by some heretofore unknown operation of natural law. It cannot bear the light—it vanishes, and the whole structure comes tumbling down about our ears. As to the persistence of the human spirit, however—"the immortality of the soul," as we call it—no science has yet been able to touch it for good or for evil; and we cling to it, because it seems both reasonable and necessary to our happiness.

One theory regarding the perpetuation of solar heat is that the sun is constantly fed by a stream of meteoric matter that is moving spirally around the sun. The theory involves the idea that all the planets are imperceptibly coming closer to the sun, and that eventually they will be swallowed up by it. Whatever our speculations may be regarding the life of the sun, we are sure of one thing, and that is that all life on our earth, all growth, and all the activities of nature, animate and inanimate, are directly dependent upon the sun's rays. If they should be cut off there would be universal quiet, which would mean universal death.

CHAPTER XIX.

THE SUN'S RAYS (EFFECT ON EARTH'S SURFACE).

In our thoughtlessness we are apt to forget how small a point of time our earth has really been a fit habitation for man. It has taken countless ages to prepare it for the higher forms of life that we find existing to-day, and the time that man has occupied the earth is a mere point as compared with the whole life of the earth.

In earlier ages the earth was inhabited by low forms of animal life, although some of them were very large and hideous in form. The atmosphere at that remote period was not pure as it is to-day, and would not support such life as we find now. At a still remoter period there was no life or germ of life, animal or vegetable, at least as we understand life to-day, for the earth was undoubtedly a mass of molten matter, and no life or germs of life could exist in such heat. I am aware that certain biologists hold to the idea that inanimate matter contains all the potency necessary for what we would call spontaneous generation.

But such proofs as are presented do not seem to me sufficient.

Then, if that is the case, you will say, there must have been a time when there was a creative act to give a start to these forms of animal and vegetable life. So it would seem, for the science of to-day goes to prove, so far as it proves anything, that all life comes from another life. Evolution does not help us, because it runs back to a primordial germ, and only indicates how the single and simple develop into the diverse and manifold. It tells How, but not Whence. Whence, then, the primordial germ? If there was a time when there was no life, then evolution makes something come from nothing. Later investigation goes to show that all life, animal or vegetable, comes from a germ having in it all the potentialities to make it develop after its kind. However much we may speculate, we know that plants and trees grow from seeds. The acorn will produce an oak and the grain of wheat other grains of wheat.

At the present day all the heat at the surface of the earth (except the comparatively little furnished by volcanoes and thermal springs, and the very trifle radiated from some of the stars) comes from the sun. The sun is such an important factor in all the operations of the solar system that we should know something of what it is. Its distance from the earth

is something over 90,000,000 of miles, more or less, according to the time of year. It is the largest body that our telescopes reveal as a globe, but not the largest in existence, so astronomy teaches. Other systems are supposed to have their suns much larger than ours. Some of the fixed stars visible to our eyes are supposed to be suns of other systems, but they are so remote that they do not affect the heat of our earth to any appreciable extent. The diameter of the sun is 108 times that of the earth, and its surface exceeds that of the earth 11,750 times. If we make a circle two inches in diameter to represent the sun we will have to make a mere dot not over one-sixty-fourth of an inch in diameter to represent the relative size of the earth to that of the sun. If we should fire a cannon-ball whose velocity, at its start, is the same as that of our Armstrong guns, it would require thirteen years for it to reach the sun if it kept up its initial velocity. Light at the rate of 186,000 miles per second requires eight minutes and eighteen seconds to reach the earth from the sun. It would require a lifetime for light to come from some of the fixed stars. So they would shine on, to our eyes, for years after they were extinct.

The sun appears to have the same material elements that are found upon the earth. This fact is revealed by the spectroscope. The

spectroscope shows certain lines that belong to the different elements when burned and viewed through this instrument. By examining the sun in the same way we find the same lines, and conclude that they arise from the same causes.

The rays of the sun have wonderful powers of analysis. When this earth had cooled so that a crust had formed, and dry land appeared, at first it was hard. But under the influence of the sun's rays for ages, coupled with the precipitation of moisture, a gradual disintegration began which released a certain portion of the oxygen stored up in the igneous rocks, which, in turn, was thrown out into the surrounding air and thus purified it. A study of the disintegrated lava-beds in the western parts of this continent show them to be very fertile for purposes of vegetable growth when sufficient moisture is present. When the mineral substances on the earth's surface had been disintegrated and prepared by ages of incessant work in nature's great laboratory, and the soil was properly pulverized, the seeds of animal and vegetable life were sown. How, we will leave the reader to conjecture. That they were sown we know. It is the province of the scientist to reveal the facts of nature as they now exist, and leave the rest to the speculation of the philosopher and the theologian. The growth of vegetation made it possible for ani-

mal and insect life to exist, and the earth teemed with both; first of an inferior kind, but later, as the conditions for a higher order of life were right, the higher order came with the improved conditions. In this way was the earth through countless ages of time prepared for man—God's highest creation.

As time progressed and new conditions arose, new germs of animal and vegetable life must have been brought into existence, or possibly diversified from the germs already existent, to take an active part in nature's grand round of life and growth. Why nature has produced such myriads of forms of animal and vegetable life has been the subject of much speculation. Some have held to the idea that many insects and poisonous reptiles have been sent as a scourge to mankind; that flies, mosquitoes, and the like were placed here to keep men from having too good a time. If this is true it would seem that the scheme does not work in all cases, for the same power that gave the mosquito his sting also gave man an intellect and made him an inventor, and one of the products of his creative faculties is a system of mosquito-bars and other defenses against these pests. It is certain, however, that the animal creation plays a very important part in the economy of nature, as we shall see farther along.

All animals, including the human race, are

sons and daughters of the sun. All the food that we eat is prepared by the sun, including the very air that we breathe. Every animal organism, besides having the power of assimilation and growth, is also a furnace in which a slow combustion is going on which keeps up the heat of the body. So that a very considerable portion of the food we eat is simply so much fuel which is consumed as such by a process of oxidation that in a stove we would call combustion. The draft to the human stove is through the lungs. The blood which has been prepared through the medium of the digestive organs is pumped into the lungs. The lung-cells are divided into two parts by a very thin membrane. One side of the membrane communicates with the outside air and the other with the blood-circulation. This membrane is porous to gases, so that the oxygen penetrates it, uniting with the hydrocarbons of the blood, and the product of this union is heat and carbon dioxide. (Carbon dioxide is a gas composed of one atom of carbon and two atoms of oxygen. It was formerly called carbonic acid.) The heat warms the body, and the carbon dioxide, passing through the membrane, is thrown out of the lungs by each expiration. You will observe that the product of combustion that is thrown out into the air by the animal is the same that comes from the chimney of a lamp or stove, to wit, car-

bon dioxide. Animal life cannot exist in pure carbon dioxide. If one should shut himself up in a room with burning charcoal, which gives off this gas in great quantities, and was obliged to inhale it, he would soon smother to death. A candle or any flame put into a vessel of pure carbon dioxide goes out immediately, as there is no free oxygen to support the flame.

One would think that, what with all the fires and gas-jets that are burning in the world, together with all the exhalations from the animal kingdom, the air would soon become unfit to breathe, especially as carbon dioxide is heavier than air at the same temperature. The reason it goes up the chimney is because it is greatly expanded by the heat of combustion. But as soon as it cools it drops to the earth. This is why it is found in wells and deep mines. I have seen a large kettle of blazing fagots put out entirely by being lowered into a "fire-damp," which is only this carbon dioxide, the product of combustion. Combustion is going on slowly in the process of decay, so that carbon dioxide comes from other sources than fires and the exhalations of animal life.

Nature, however, has provided in a beautiful way a means of taking care of this surplus gas that is poisonous to animal life. Plants and trees and all sorts of vegetation

thrive upon what the animal rejects as poison. The leaves of trees take up this poisonous gas and live upon it, in connection with moisture, and the little that is drawn from the earth, so that there is an eternal round of inter-relation and interdependence between the animal and vegetable kingdoms. Here we have found at least one very important use for the abundant animal life in the natural world.

But you say this constitutes a perpetual motion. It would if we had told the whole story. This operation could not be carried out without the aid of the sun. The leaf of the tree is nature's great laboratory. Through it she carries on some of her most wonderful operations. In it are appliances for analysis transcending all those in all the artificial laboratories of the world. Here water and carbon dioxide are decomposed, the tree or plant incorporating the carbon and the hydrogen into the woody fiber while it gives back to the air pure oxygen, which is the life-giving principle of animal existence. The magical power that is able through the mechanism of the leaf to accomplish this miracle of miracles is the quiet sunbeam. Silently, from day to day, this wonderful power, without which all activity of every name and nature would cease, is storing up its energy in the vegetation of the world, and through the vegetation is supporting the lower animal, and directly, as well as through the

lower animal, man. There is food in grass, but the human stomach could not extract it, as there is too much that is not food mixed with it. The ox is organized for appropriating such food, and through the flesh of the ox man gets it in a condensed state.

We have seen that all the combustible material on the earth, and under the earth, has been put there at some period by the action of the sun's rays. All the coal, all the oil, all the natural gas under the earth, and all the wood on the surface of the earth, is simply so much stored energy; a great weight, as it were, wound up by the magic power of the fluttering leaf acted upon by the sunbeam, through ages of time. We dig the coal, we ignite it, and a mighty steamer plows the ocean by an energy that the sun has stored away ages ago, and now has been released by striking a match. Thousands of people on thousands of railroad trains are flying here and there all over the civilized world by an energy that was stored thousands of years ago. All the wheels that turn, in all this wide, wide world, all the winds that blow with all the waves they create, all the tornadoes and cyclones, all the rains of summer and the snows of winter, all the thunder, lightning, and hail, can be traced to one common origin—the sun. And this is not all; every man, animal, or insect, every living thing that now lives, or ever has lived, either

animal or vegetable, owes its life directly to the same source.

When we see a vast conflagration we wonder if there is any power that can restore the apparent destruction. Yes, a way is provided; a few years of sunshine and all is restored. Our homeopathic friends have a motto, "Similia similibus curantur"—"Like cures like." The destruction caused by heat is restored by heat. The products of combustion arising from the burning building are gathered up, and by the magic of the sun's rays acting through the leaves of the forest new wood is formed, and more energy is stored. The amount of energy stored in a cubic foot of the best coal is equal to a power that would raise a weight of 3,660 tons 100 feet, or 732,000,000 pounds one foot. This statement supposes that all of the energy stored in the coal is converted into mechanical energy. In practice only about 5 per cent. of the energy of the fuel burned under a boiler is converted into mechanical work. The problem of increasing the percentage of work obtained from a given amount of heat-energy liberated by combustion has been worked upon by many inventors, and as yet with only partial success. When we are able by simple means to utilize the changes of temperature as a motive power we shall no longer be dependent upon fuel-combustion as a source of heat. When the

energy expended in contraction and expansion, caused by the daily changes of temperature, can be utilized to drive our dynamos, then from these we can obtain heat, light, and power to minister to our bodily comfort and to carry on the activities of every-day life. You ask, Why not utilize the direct rays of the sun, or the force of the winds? We could use these, but the sun does not always shine, nor does the wind always blow, while changes of temperature always occur, once at least in twenty-four hours.

Another effect of the sun upon the earth's surface is seen in the tides. It is a common notion that the moon controls the tides entirely, and to the largest extent it does, simply because it is so much nearer to the earth than the sun. The effect of the sun may be seen in the greatest degree at such times as the sun and moon are pulling together in a direct line upon the water of the ocean. Their combined attractions, when there is complete co-operation, cause a much higher tide than at other times. (See Vol. I, "Tides.") But when the sun and moon are so related in their position with reference to the earth as to work against each other, the result is a much lower tide. If each had the same influence upon the earth as mere attractions, there would be times when the tidal wave would be entirely neutralized if the forces could be properly re-

lated, just as two sound-waves will neutralize each other when they are of the same amplitude and related in a certain way. It will be seen that it is not the heat of the sun, but its attraction, that produces the tidal effect. In all other respects its power on the earth is greater than that of the moon. The moon can shine only because the sun shines upon it. It has no luminous qualities of its own. In fact, the sun may be said—in a sense—to be the whole and only producer of the tides, because, in all probability, the moon is indirectly a creature of the sun, and at one time was part of it. In this aspect of the case, the moon's power over the tides is only a power that was delegated to it by the sun.

Taking once more a large view of these interchangeable forms of energy working through matter, let us return to our earlier conclusions: First, Matter is indestructible. We may rend it asunder, atom by atom. We may subject it to the most intense heat known to nature, and still the matter exists in some form. And if you gather it up, from all the hiding-places in the material universe, and weigh it, you will find that none has been lost. The measure of matter, then, is Weight. So with Energy; it disappears perhaps for ages, but under certain circumstances it will reappear and do the same work that was expended in storing it away. Energy, like matter, is in-

destructible, and the measure of energy is Work. What shall we say of the Intelligence that plans all this? Can the Creator be less than the creature? Shall we not say that Intelligence is indestructible, and its measure is its Power to adapt means to ends? Intelligence, Matter, Energy—nature's trinity in her manifestations.

CHAPTER XX.

LIGHT: THE SCIENCE.

The history of light as a science has been one of progressive steps from small beginnings; and this may be said of all the other sciences, mental and physical. The earliest writings on the subject are those of Euclid, about 300 B.C. Before this Pliny and Aristophanes speak of burning-glasses which produced combustion when held to the sun. Globes of glass were also used by the vestal virgins to kindle the sacred fires. Surgeons, too, used glass globes to cauterize the flesh of sick people.

Among the early speculations on the subject of vision were those of Pythagoras and Plato. Pythagoras held that bodies became visible by an emanation from objects that entered the eye, while Plato—just to be a little different—held that there were also particles projected from the eye that met those coming from the object seen, and both emanations were returned to the eye. The only step made by the Platonian school was that they announced

that light traveled in straight lines and that it was reflected; also that the angles of incidence and reflection are equal. Aristotle made a small contribution to the science in describing some of the phenomena of the rainbow.

Ptolemy, the astronomer of Alexandria, born A.D. 70, was the first to give the science a standing by writing five books on the subject. He held that visual power proceeded from the eye, and that the reason old men could not see as well as the young was due to a decay of the "visual virtue." He was, perhaps, the first to show that light was refracted as well as reflected. He lays the foundation for the explanation of the phenomena of mirage, which will be discussed in a future chapter. Galen, a Greek physician, who lived about 130 A.D., made some contributions to the science, but for 1,000 years after his death no progress was made, and this as well as the other sciences were swept out of Europe; and after this long period it took root in the soil of Arabia. During the Dark Ages almost everything in the way of learning perished in Europe for more than 1,000 years, owing to the vast hordes of ignorant people that overran that continent during this period.

About 1,100 A.D., Alhazen, an Arabian mathematician, made some important contributions to the science of optics; at least he gave it a

fresh impulse. He held to the idea of Pythagoras, that we all see by particles that come from the object to the eye. Following Alhazen, we have Roger Bacon, born A.D. 1214. He is supposed by some to have invented spectacles; at least he seems to have been acquainted with their use. A writer in 1551, referring to "Friar Bacon," says in old English: "Great talke there is of a glasse he made at Oxford, in which men might see things that weare don, and that inged to be don by power of euvill spirites. But I know the reason to be good and natural and to be arright by geometry, and to stand as well with reason as to see your face in a common glasse."

There is much interesting reading as to the priority of the invention of spectacles by different claimants, which goes to show that human nature has not undergone much change since the thirteenth century. From spectacles came the important invention of the telescope by a spectacle-maker by the name of Zacchias Jansen. He lived in Middleburg, in Walcheren, and made the invention in 1590. This invention was first used by Galileo, who made many brilliant discoveries in astronomy soon after. He discovered the satellites of Jupiter, the structure of the Milky Way, the phases of Venus, the rings of Saturn, and the spots on the sun. A long list of thinkers since the time of Galileo have contributed to the evolu-

tion of the science of optics. Among them the immortal Newton.

It was not until the early part of this century that the dynamic or mechanical theory of light was fully promulgated, or if not fully promulgated, at least the solid foundations of the system were laid. The champion of this theory was an Englishman by the name of Thomas Young, born in 1773. Since the time of Young much has been added confirmatory of the truth of the theory, so that to-day it may be said to be established and to explain all the phenomena of light and radiant heat and is helping us to an understanding of electricity.

Every important discovery establishes a closer kinship between the sciences. The time has already come when to know any one of the sciences thoroughly it is necessary to know the rest; in fact, all the so-called natural sciences are different branches of one great science. It is doubtless true that there is but one energy, and it may be that there is but one element of matter out of which all the various so-called elements come.

Artificial lighting has made wonderful progress, both in the means by which it is produced and its applications for public and domestic purposes, within the last two decades. The great advance in modes of lighting has come largely from the wonderful strides made in the

science and applications of electricity within the last twenty-five years. The electric light has stimulated the producers of gas to make improved methods of burning their products in order to get the greatest amount of light. Systems of incandescent films or mantles, heated white by the combustion from a gas-jet which they cover, have come into use, that have been the outcome of a suggestion taken from the incandescent electric lamp. From a sanitary point of view the electric light has no rival. All other systems of lighting, where there are open burners, are throwing out into the room continually the product of combustion, carbon dioxide, which vitiates the air and should not be taken into the lungs if possible to avoid it. It will be our endeavor in the chapters following to give an explanation of the fundamental phenomena of light so far as the science is at present developed.

CHAPTER XXI.

LIGHT AND ETHER.

We now come to a subject that, perhaps, most people would consider the greatest in importance of all the means by which the inner man has communication with the outer world. If we had our choice between losing our sight or hearing I think most of us would cling to sight. Some perhaps who live in the world of musical sounds would prefer hearing.

This medium of communication we call light. Light, like sound and heat, objectively, is motion or vibration; subjectively, it is sensation. It is unlike sound in that it cannot be transmitted through the medium of material substance, as commonly understood; but like radiant heat it is transmitted through a hypothetical medium called Ether. This medium has been referred to in the chapters on Heat, but a short repetition of it here will not be out of place. The ether is supposed to fill all interstellar space as well as all interatomic space of all substances, however dense they may be. It is so refined that it penetrates the

pores of the most solid substances, and no vessel can be made of any material that will hold it. If we exhaust the bulb of an incandescent electric lamp the air-molecules cannot pierce it and we say that we have a vacuum. So we have, so far as air or any of the gases are concerned. But it is not ether-tight. It is like a coarse sieve to the ether, which passes through the spaces between the atoms with almost, if not quite, the same facility as in space itself. The ether must be a substance of some kind, and has density and elasticity, otherwise it could not transmit light and radiant heat at the enormous rate of speed that it does. When we speak of density in connection with the ether we mean dense in the sense that there are no spaces between its particles—if particles there are—as is the case with ordinary matter. In the ordinary sense it is the least dense of all things. The ether is homogeneous, and most likely continuous—without molecular structure.

And all kinds of matter may be only different affections of the one substance, ether, as it is related to motion. An atom of gold may only be a minute whirl in the ether that gives it a certain hardness and color—properties that may be due to the peculiar form or rate of motion imparted to it. A different form or rate of motion may determine all the charac-

teristics of all the other so-called elements of matter. The ether may be the one elemental substance out of which all forms of matter have their origin. A discovery of the true nature of this hypothetical substance would be a great boon to the physicist—and would lead to the explanation of much that is now in the dark, especially in the domain of electricity.

Light is propagated by waves that are said to be transverse, while those of sound are longitudinal. Light-waves are supposed to be magnetic waves, by some, and there is much of evidence that points that way. We know that there are magnetic waves in the ether that travel at the same rate as light-waves, and that there are nonluminous waves as well as luminous. They become luminous only when the rate of vibration is sufficiently great.

The slowest rate of luminous vibration is that of the red ray, which is 477,000,000,000,000 per second, while the highest visible rate is 699,000,000,000,000 per second. This phase of the subject will be more fully discussed under the head of Color.

All bodies are either luminous or nonluminous. A luminous body can be seen by its own light, but a nonluminous body is seen by reflected light, and most bodies are nonluminous. A flame of any kind is luminous, and anything that is heated to a certain point be-

comes luminous. If we heat a poker to a red or white heat it is called luminous; before heating, it was nonluminous. The sun is the great luminary of our great solar system, but there are other suns belonging to other systems that are supposed to be larger than ours. The moon is supposed to be a dead cinder, having no life or vegetation. It is nonluminous, and, like a great many people in this world, it shines only by a reflected light. Some of the stars are self-luminous, and others shine, as the moon does, by a light that is reflected from some luminous body.

Light travels at the enormously high rate of 186,000—and according to some authorities 188,000—miles per second. To travel at this rate, as I have said before, there must be some very elastic medium for it to travel through. Very great elasticity is inconsistent with the idea of a fluid as we understand fluid; and at the same time the ability to pass through such fine pores as those of glass, for instance, is inconsistent with the idea of a solid. This is mere speculation and will be taken for what it is worth. We are sure of the facts regarding sound, heat, and light, to wit, that they all exhibit the phenomena of motion, the rate of which is measurable.

If I could wave my hand back and forth forty times per second you would hear a low musical note. If I could increase it gradually

up to 40,000 vibrations per second you would have heard all the phases of audible musical tones, so far as they are related to pitch. At this point the ear, owing to its limitations, refuses to accept a higher rate of vibration than 40,000 as sound of any kind. But vibration goes on, and we have no more right to say that there are no sounds not heard by ordinary mortals, above 40,000, than the man has, who can only hear up to 30,000 (and there are some), to say that there are no higher tones simply because he cannot hear them. I know there are people who hold that sound is not sound without an ear that can hear it, but that is a mere quibble about words and should not be dignified with a discussion. I have said that sound objectively is motion, and subjectively it is sensation, and that covers the whole field—so far as definition is needed.

But to go back to our illustration. If I could increase the motion up to 477,000,000,000,000 times per second you would begin to hear again, through your eyes, but the motion would not be carried to the eye through the medium of the air—for the air is far too inelastic a medium to respond to such rapid motions—but through the highly elastic ether that we have described.

I hear some one say, "Stop talking about ether and vibrations and all such, and tell us how we see things." Well, I will make it as

plain as possible, but a man cannot work without tools, and ether and vibrations are a part of the outfit that the scientist needs, to make himself understood. So you must use the eye of your imagination and view with me the unseen things in order that the things seen may be explained. If a man who had never seen water were shown a ship and told that it had been floated from a point 2,000 miles distant, he would not get much of a notion of what that meant unless first the nature and properties of water were explained to him, in its relation to other things. If a man is told that light comes from a point in the heavens, ninety millions of miles away, he wants to know how it comes and what kind of a vehicle brought it. When we talk about ether and vibrations we are trying to explain the vehicle and the law of its operation.

If we shut ourselves up in a room without windows, we are in darkness, and although there are many objects in the room, such as furniture, pictures, etc., we do not see them any more than a blind man would, and the only idea we can get of what is in the room is by such crude notions of form as we can get from the sense of touch. Suppose there is an incandescent electric lamp in the room and we turn it on, what has taken place? Now we can see all the objects in the room and can tell their form and color. Remember now what we

have said about the nature of ether, the medium through which light is transmitted. The electric current flows through the carbon filament inside of the globe, which is a vacuum, and as the filament is a poor conductor of electricity a part of the electrical energy is converted into heat (which always happens when an electrical current is resisted), and the heat becomes so intense as to produce a vibration of the particles of the carbon at a rate of over 400,000 billion times per second, and this causes the ether in which it floats to vibrate in sympathy so that the ether that fills the room is thrown into different rates of motion corresponding to all the colors of light. This ether-vibration is reflected from the object that we happen to be looking at, to the eye, which takes up this motion—just as the ear does that of sound—and transmits it to the brain as motion, and there motion becomes sensation, and we call it Light. And it is through this medium of motion that we are able to discover the color and shapes of objects in the world outside of ourselves.

How wonderfully beautiful are the operations of the laws of nature in their relation to man as a thinking, reasoning, and emotional being! How wonderfully they are adapted to his needs as guides, not only through this transient shifting world in which we live, but as suggestions pregnant with meaning as to

what may be in store for him the great untried beyond!

White light, such as sunlight or the electric light, does not come from one single rate of vibration of the ether, as we shall see, but is a combination of all the colors of light. Light is absorbed, reflected, refracted, and dispersed, and other phenomena called interference and polarization belong also to light. We see that sound obeys most of the laws of light, for sound is reflected, absorbed, refracted, and furnishes the phenomena of interference the same as light. If light shines on a black surface all of the rays are absorbed and none are reflected back to the eye. If there were no clouds or atmosphere and all substances were black there would be practically no light. We could turn ourselves toward the sun and see this luminary because the rays come direct to our eyes and do not have to be reflected, but the moment we turned toward other objects all would be dark, because there would be no substance that could reflect the light to our eyes. We see or get an idea of the shape of things that are dead black, much as we see a silhouette picture. As we have seen, white objects reflect all the colors of light, and all the colors of light mixed in the proportion that they come from the sun produce the sensation of whiteness. Absolute black absorbs all colors, as absolute white reflects all. Other

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substances have the power to absorb some and reflect others; these objects are neith— black nor white, but some shade between the two.

There are seven fundamental colors called the prismatic colors, or the colors of the rainbow. These colors may be seen by passing a ray of sunlight through a prism, which disperses or changes the ray from its composite character into its fundamental units. These colors are found to be red, orange, yellow, green, blue, indigo, and violet. If all these colors are mixed together we have white light again. When light has been resolved into its primary colors the result is called the spectrum of that light. In this way we may take different shades of color and resolve them into their elementary colors by a process of analysis, similar to the way a musical tone of a certain quality or tint may be analyzed, and determine just what its composition is in reference to its overtones or sound-tints. In our next chapter we will take up the subject of color and how it is produced, and what it means both in a physical sense and as it appeals to the consciousness as sensation. Also in future chapters, what the relation of color is to music in its effects upon our emotions.

CHAPTER XXII.

COLOR.

In the musical scale each note differs from the other in the matter of pitch; and pitch, as we have seen, is the rate of vibration per second. Colors differ in pitch the same as musical tones, and there are about an octave of them. If we allow a beam of sunlight to come into a dark room through a small aperture and let it fall on a white screen, there will appear a round spot of white light that is an image of the sun. If now we intercept the beam of light with a prism placed with the edge downward there will appear on the screen a band of colors, one above the other. They will appear in the following order, beginning at the bottom: Red, orange, yellow, green, blue, indigo, violet, and the whole is called the solar spectrum. When a ray of light passes from a rarer to a denser medium—as from air through glass—the rays are bent out of their course and the bend is different for each color. This bend is called refraction. The red ray is the least refracted and the violet the most; and this is why the violet ap-

pears at the top of the band of colors. This difference of bend in the color-rays is due to the difference of wave-length. For light, like sound, has a definite wave-length for each vibration-period. In order that we may better understand, let us go back a little and tabulate the vibration-period of each color:

Red	477,000,000,000,000 per second
Orange	506,000,000,000,000 per second
Yellow	535,000,000,000,000 per second
Green	577,000,000,000,000 per second
Blue	622,000,000,000,000 per second
Indigo	658,000,000,000,000 per second
Violet	699,000,000,000,000 per second

x

It will be seen from the foregoing table that the vibration-rate per second increases from red to violet. The wave-length of the slowest vibration, to wit, red, is the greatest, the same as in sound, and the shortest is that of the most rapid,—violet. The more waves there are in a given distance the greater the bend will be in passing from one medium to another.

The red ray has 39,000 waves to an inch, hence the wave-length of red is one-thirty-nine-thousandth of an inch. The violet ray has 57,000 waves to the inch. The red ray, having the fewest number of waves to the inch, is therefore bent out of its course the least, while the violet ray, having the greatest number per inch, is bent the most out of its

course in passing through the prism. It will be seen from the foregoing why the colors are dispersed in passing through the prism.

It will be remembered that the wave-length of a sound-tone with 256 vibration-periods per second was four feet and four inches in air. It will be noted that there is a vast difference between the wave-length of a sound-tone and that of a color-tone.

You ask, why do different objects seem to have different colors? Color as a sensation is the effect of ether-waves impinging upon the retina of the eye. When these waves enter the eye at the rate of 477,000,000,000,000 per second there is a sensation produced in the brain that we call red, but when the retina is agitated by 699,000,000,000,000 ether-waves per second we experience the sensation of violet, and the same is true of the other colors; so that for each variation of rate within the limits of color there will be a corresponding variation of color-sensation. Having now established the rates of motion and the wave-lengths of the different colors of light, we are prepared to explain the phenomena of color as they appear on various objects that come within the range of our vision.

It has been stated in a preceding chapter that we see all nonluminous objects by reflected light. If a ray of white light falls upon a black surface all the colors are absorbed and

none reflected. Darkness is the absence of light, hence we have black, which is simply the absence of all color. If a ray of light falls upon an object that absorbs all the colors but red, then red alone will be reflected to the eye and we have the sensation which belongs to that color, because the rate of vibration that produces this sensation of red is the only one that is reflected. This same thing would be true of all the colors. If an object has a violet color it is because all the other colors are absorbed and violet only is reflected to the eye, hence the sensation of violet.

When a color is absorbed it becomes heat. If we wear dark clothing the sun will seem much hotter than when we are clothed in white. The former absorbs the color-vibrations, which become heat, while the latter reflects them. If we have some color-tint which arises from a mixture of colors it is because the object so tinted is able to reflect two or more color-vibrations, the resultant of which is the tint. Colors, like sounds, may be mixed in an infinite number of proportions, and each change of proportion is not only a change of the physical conditions of the ether between the reflecting substance and the eye, but a change of sensation, or emotion. The blending of color-motion affects our emotional nature somewhat as the blending of sonorous tones does. They may be harmonious and pleasing, or they may be inharmo-

nious and irritating. Women are as a rule more sensitive to color-tints than men, because their training has been such as to make them so. We hear them say, "Those colors fight," which is another way of saying that they are inharmonious and grate upon their sensitive nerves.

Color-art is not yet developed so that it is a language of the emotions in the same sense that music is. Not long ago it could have been said that music was not an art. It may be that at some future time the art of color, so crudely developed now, will be brought to the same state of perfection as a language for the expression of emotion that the art of music has reached at the present time.

It will be impossible to give you more than a very few fundamental facts relating to this beautiful science, because so many of the phenomena, to be understood intelligently, need the aid of experiment and illustration that cannot be had here. The fundamental thought running through all the phenomena of sound, heat, and light, as well as electricity, is Motion; motion, as related to our sense-perceptions, and motion as related to all the innumerable phenomena of nature.

Let us now continue our investigation of color, from the standpoint of definite rates of motion and definite lengths of impulse. Every schoolboy is familiar with soap-bubbles,

and has spent many a happy hour blowing them. But he did not realize how many scientific truths could be extracted from them. The study of soap-bubbles has led to some of the greatest discoveries.

I am aware that there are a certain lot of pleasure-seekers, with more money than intellect, who look with pity akin to contempt upon a man who could waste so much good time in the study of such simple things. Don't waste your sympathy, dear friends; he pities you even more than you do him. He sees in the soap-bubble, among other things, an apt illustration of your own gilded life. For one brief moment it floats in the sunshine, arrayed in gorgeous hues, surrounded by admiring onlookers--when lo! the bubble bursts and it is no more. You mourn the loss of its gorgeousness, but to you it has no meaning beyond. The man of science sees in it the illustration of natural laws that are transcendently beautiful. The great Sir Isaac Newton made some of his most important discoveries by studying soap-bubbles. Day after day he sat in his back yard blowing them and watching them rise in the air, displaying those varied hues of color that any one may see by trying the experiment. His neighbors became alarmed and took council among themselves as to what should be done for the "poor man." Poor, indeed, he was to those ignorant souls.

But how rich was his life to the millions who have followed him!

For getting the finest results in the formation of soap-bubbles, the best medium is a solution of castile-soap and glycerin in the proportion of one part glycerin to two of the saturated solution of soap. First take a common glass tumbler and dip the mouth of it into the solution and by careful handling we can get a film of soap and glycerin stretched across the mouth of the tumbler. Now turn the tumbler over on its side and immediately bands of color will appear running across the film. You will notice that these colors change. We have already seen that every color has a definite wave-length and a definite rate of vibration per second. A color will be reflected from the film when its thickness is one-fourth of the wave-length that belongs to that color. We saw that when sound was reflected or re-enforced by a hollow tube closed at one end the tube was one-fourth the length of the sound-wave. The same law holds good with color-motion. The reflection is from the back of the film, as sound is from the bottom of the tube. If the film is thick enough the first color that will appear is red, and after that the others in the order of their succession in the solar spectrum. The film is constantly growing thinner at the top, by the stretching produced by gravity, and when it

reaches the thickness of one-one hundred and fifty-six thousandth of an inch the red ray will appear, as that is one-fourth the wave-length of the red ray. When all the phases of color have appeared and passed down there appears a patch of gray at the top of the film which tells us that it is stretched to its limit. And now it breaks. Knowing as we do the wave-lengths of color, we are able to measure the thickness of the film. If violet has appeared on the film we know that it is not over one-fourth the thickness of a wave-length of that color, which would be one-two hundred and twenty-eight thousandth of an inch. This gives us also some idea of the size of a molecule of water, as the film cannot stretch to a thinness beyond the diameter of the molecule; although the film may break by its own weight long before its thickness has been reduced to that diameter.

Light-waves may be made to interfere with each other the same as sound-waves. If two sets of light-waves of the same wave-length are so related to each other that one set of waves fall in the depression between the other set, the result is darkness.

We have seen that if all the colors of a sunbeam are totally reflected to the eye from an object, the color of the object is white. But if some one of the colors is only partially reflected or entirely absorbed, the composite ef-

fect would be something away from white. There is an inconceivable number of variations and proportions of color, and as each variation may produce a variation of tone, or tint, we can see how all the delicate shadings of a poem or a symphony in color may be produced. Some time color and color-tones may be classified and arranged in their order of succession and combination, and by some sort of instrument that will cause them to appear and disappear—played upon as we do upon a musical instrument to produce the effect of sound-coloring. Color will then become a language of emotion, as music is now.

CHAPTER XXIII.

TRANSPARENCY.

Light is energy, and can do work. When its beams are thrown upon a photographic plate it impresses itself upon the molecules of the preparation upon the plate, and leaves an image of the object that was reflected upon it. If we expose any black substance to the sun's rays, the light is absorbed and becomes heat. If a body is white it reflects the rays, and the body or substance is kept cool.

Take a poker that has a polished knob on one end, while the other is a dead black, and hold both ends to the fire so that each has the same chance to be heated. As soon as the dark end has become too hot to handle try the bright end, and it will be comparatively cool, because the radiant heat has been reflected away, while at the black end of the poker the radiant energy has been absorbed. If we hold a piece of clear glass plate toward the sun the light-rays will pass through the glass without interference, and the plate will not be heated. If, however, we blacken one side of the glass plate with a heavy coating of lampblack, and

then expose either side to the sun, it will become heated, as the lampblack will arrest the sun's rays and convert them into heat. This leads up to the subject of transparency.

Some substances are said to be transparent and others opaque. When the light-rays will pass directly through a substance without interference, and we can see objects through such substance, it is said to be transparent, but when the light-rays cannot pass through a substance and we cannot see through it as we can through space or through a transparent substance, we call it opaque. What is the physical difference between the substances? It is purely one of molecular structure. In the former case the molecules are so arranged that the light-rays can pass directly through the interatomic spaces between the molecules in a straight line without interference. In the latter, or opaque, substances, the molecules are so arranged that there is no direct road through the substance. In another chapter we explained that, while glass was water-tight it was not ether-tight; nor is any substance ether-tight. To the ether the glass is like a sieve, and so is any substance. Light-waves fly in straight lines. The openings through the glass are probably straight, so the light can pass directly through, but the openings through an opaque body are crooked; the molecules overlap in such a way that there is

no direct line through the substance, hence the light will either be absorbed or reflected when it strikes upon an opaque body.

Some idea of what we mean by the overlapping of molecules may be had by the following experiment. Fill a tube with finely pulverized iron filings made into a thin paste. Let the two ends of the tube be stopped with glass heads. Throw a strong beam of light on one end so that the direction of the beam will be in the direction of the length of the tube. Place the tube into a helix (a coil of wire), and pass a current of electricity through the wire of the helix. Now so direct the arrangement that the beam of light strikes upon a screen, and a spot of light will appear on the screen as long as the current is passing; when the current is broken the spot of light will disappear. The magnetism rearranges the particles of the naturally opaque mass of iron filings so that light can pass between them: they are transparent. When the current is taken off the magnetism disappears, and the particles arrange themselves again in such a way as to shut off the light: the body becomes opaque. This may illustrate, in a crude way, the difference of molecular structures between a transparent and an opaque body.

Farther back in this chapter we saw that sunlight will pass through glass, which is transparent, without seeming resistance, and

the glass will not be heated. This is because the light-rays are not absorbed. But some substances are semi-transparent; some of the color-rays can pass through and others cannot. The ether-spaces between the particles are such that colors of certain wave-lengths can pass through but others cannot. If we pass a ray of light through a solution of sulphate of copper—which is blue—the blue ray will pass freely through, but the others are arrested. If now we pass a ray through red glass, only the red ray comes through it; all that the blue solution transmits the red cuts off, and the red transmits all that the blue cuts off. If we pass the beam through both, no color comes through; the two together constitute an opaque body, while by themselves they are each semi-transparent bodies. There are all degrees of transparency, or, if you prefer, there are all degrees of opacity.

A beautiful and instructive experiment may be made with a solution of the permanganate of potash, which is transparent to two colors only. If we pass a beam of light through this solution upon a screen, the composite effect of red and blue will be most gorgeous. These two colors only will pass through, while the other colors are entirely absorbed. The interatomic spaces in the solution are so related to the wave-lengths of the colors that only two colors, namely, red and blue, can pass through

unimpeded. Now introduce a prism and separate the beam that has passed through the solution and we have two spots of color, one blue and the other red. In the center the spots overlap, and at that point we will have the composite color as it was before the prism was introduced.

I once had an opportunity to observe the wonderful rapidity with which light and radiant heat are transmitted through glass, which is transparent to both. I was at Vancouver, at the terminus of the Canadian Pacific Railway, on Burrard Inlet. We started for Winnipeg about noon, and six miles out the train was stopped by a burning woodpile of large dimensions, within a few feet of the track. After two hours of waiting the wood had been reduced to a huge pile of glowing coals. The conductor concluded to run past at a high rate of speed; so backing up about one-half mile they put on a full head of steam and ran past the fire at a tremendous speed. I was in a stateroom, and the passageway around it was between me and the fire, so that the heat and light had to pass through two windows before it reached me. I stood in the stateroom, looking in the direction of the fire, so as to get a glimpse of it as we ran by. The time that my face was exposed was only a small fraction of a second, and the heat had to come through the glass of two windows some

distance apart, and yet my face was burned to redness. The glass was not heated, but the sides of the cars were burned into blisters. The one was a transparent and the other an opaque substance.

CHAPTER XXIV.

MIRAGE.

A light-ray in passing from one transparent medium to another, differing in density, is bent at the point it enters. This bending of the light-ray is called refraction. If we put a stick into the water at an angle with its surface the stick will appear to bend upward at the point it enters the water, while the light-ray really bends downward. We ought to have a diagram to make it plain, but if you will follow me closely I will try to give you a mental picture of the phenomenon.

First, place a tank, something like an aquarium, filled with water, in a dark room. Admit a small beam of sunshine through the shutter, striking the top of the water at an angle, say, of 45 degrees. If the room is dark you can see the beam of light as it passes through the air, for it illuminates the particles of dust floating in the air. When it strikes the surface of the water it is bent downward. Now let us put a coin on the bottom of the tank just where the beam of light strikes it, and put a screen of some opaque substance on

the side of the tank from which the beam of light comes, and raise it up till it just touches the lower edge of the light-ray. Stretch a string along the path of the beam of light and fasten it at both ends—so as to mark its angle and position. Now open the shutter and flood the room with light; place your eye in the path of the beam that is now marked by the string and you can see the coin at the bottom of the tank, although it is really hidden by the screen if you look toward it in a straight line. The coin will appear to be in a direct line with the string, but it is not.

Leave the string, coin, and screen in position, and run the water off, and then place your eye in the same position as before when you saw the coin and you will find that you cannot see it, for it is hidden behind the screen. Draw a line to the bottom of the tank in line with the string and the point where it strikes the bottom is where the coin appeared to be. Place another coin at this point so that you can just see it over the top of the screen if you look from the same point as before. Now fill the tank with water again and look from the same view-point, and lo! the first coin has come into view in line with the string, while the second has moved forward out of line with the string. You observe, then, that by this means we can see around a corner. But the object under these conditions is never

where it appears to be, for it will always appear to be in a direct line with the direction that the light-ray—that is reflected from the object—enters the eye.

Light is refracted differently in different media. It is refracted as it passes through the air unless the air is the same density all the way from the object to the eye. If we are looking through the air and there is a gradual change of density between us and the object we see, there will be a gradual curve in the reflected light coming from the object to us, and the object will appear to be in the direction that the light enters our eyes. The distance its true position will be from where it appears to be will depend upon the amount of change in the density of the media through which we are looking. This phenomenon we call mirage. Many times those of us who live on the lake-shore have seen this phenomenon when looking off on the horizon on a summer day. Sometimes the sand-hills of Michigan City, on the east shore of Lake Michigan, may be seen from the opposite shore looming up in the air, when in fact a straight line drawn from a point on the shore at Michigan City and elevated just enough to clear the surface of the water would clear the tree-tops on the opposite shore. So that when we see the sand-hills from the west shore we see by curved rays of light extending across the lake. Sometimes an

image of the water-line on the horizon will be thrown up into the air with perhaps a picture of a ship on it, and we often can see the sky under the ship-picture, but not the ship itself, of which that is a reflection. Many times we see the sun after it is below the horizon, by these refracted rays.

There is another phenomenon that is called mirage, that may be seen on sandy plains or deserts on any very hot day. The sand becomes very much heated and a stratum of heated air is formed close to the ground which makes the density of the air increase upward, for a distance, forming a line of condensation which acts as a reflecting surface for light, and it has the appearance of smooth water. Any one seeing it for the first time will declare that it is water, and in fact the deception is perfect, as I have occasion to know. I was once traveling through what is called Smoky Valley, in Nevada, on a hot day. About 2 o'clock in the afternoon we came in sight of a large body of water many miles in extent, as it appeared to me. It was a lake of wondrous beauty, with a smooth surface. The mountains and trees were reflected in the water in inverted position, as all of us have seen in other bodies of smooth water. I imagined that I could see towns and cities scattered along the distant shores, and the deception was so perfect that for the time I could not

believe it was not what it seemed. My companions were natives, and, knowing that I was a "tenderfoot," were disposed to have a little fun; and they had it. They had names for the towns, as well as the lake, and I got a lot of information regarding the industries carried on there. I could discern sails in the haze of the distance, and imagined I could see moving trains and hear the whistle of locomotives. After I had enjoyed this spectacle for an hour or more, as we jogged slowly along in our wagon, and the natives had had untold fun in a quiet way, the whole thing suddenly picked itself up and got out of sight. I knew then that I had been witnessing an unusually fine exhibition of mirage on the desert.

There is another kind of mirage that is much more common than the natural phenomenon that I have been describing, and while it does not strictly belong in the category of natural science, there is a sense in which it does. It may be styled mental mirage, and consists in the distorted conceptions of various subjects and things that we see through a distorted mental atmosphere, which is largely one of our own creation.

Man is to a large extent a creature of circumstances and environment; not wholly, as that would take away his free agency and make him in no sense the architect of his own fortune. Every man of strong individuality is

the latter, to a large extent, but he is a strong man indeed who can resist successfully the molding influence, first, of heredity, and after that the almost irresistible power of education in any particular line. He cannot resist entirely the prejudices of early training and surroundings, whether they appeal to his reasoning powers or not. This is especially true when applied to the dogmas of religious sects and the so-called principles of political parties. The average good citizen of any religious sect or political party sees clearly, in common with his brethren of other sects and parties, in direct lines through the atmosphere of common interest, common brotherhood, and sometimes common sense. But as soon as the rays of his mental vision strike some denser, or, it may be, rarer medium of prejudice of party, church, or society affiliation, a refraction takes place, and we have the phenomenon of mental mirage. The truth may lie in a direct line ahead, but he is really seeing in a different direction because of the refracting or distorting power of a prejudice.

Science has no prejudices—though scientists often do. Science is like figures: they do not lie themselves, but the men who figure are often the greatest liars in the world. Science, per se, is formulated truth. Its aim is to get at the truth about everything. Taking this view of science, it is the most important study

that man ever engaged in. So much of human effort has been and is spent in combating things that are non-essential, that too little co-operative work is done in the direction of determining the great essential truths. In one of the chapters on Sound it was shown how one musical tone of the same power and pitch, and even of the same quality, as that of another just like it, might be entirely obliterated by the manner in which they were sounded in relation to each other. It was also shown that there was an easier way to sound both together so that each would re-enforce the other and thus double the tone instead of the one entirely destroying the efficiency of the other. So it is with human effort. Co-operation will accomplish wonders for good, while the opposite only leaves a dark void that is the darker because of the misguided effort put forth, that other men have not only seen, but have felt its blighting influence.

Another phase of mirage, as seen in natural phenomena, is its complete deceptiveness and its ability, owing to the peculiar atmosphere by which it is surrounded, to stimulate the imagination. In the hazy outlines ghosts of shapes become real things, and the heated wave-motion of the atmosphere easily gives life to imaginary men and animals and motion to sailing vessels and steam-cars. Mental mirage is more potent in its deceptiveness and

more powerful in its influence over the imagination than its counterpart in the natural world; and has the disadvantage of not yielding so readily to the power of analysis and being so susceptible of explanation.

One of the great advantages derived from the study of natural science is, that it is usually studied for its own sake and for the object of arriving at the truth whatever it is. The scientific investigator must have no prejudice not founded on fact, and when so founded it is no longer a prejudice. He must not allow the religious dogma or the political principle to enter or become one of the factors in his search for truth, but when he has found the truth it may shape the dogma, destroy or confirm the political principle, according as they are found to be in or out of harmony with the facts. Facts are stubborn things, and it is worse than useless to try to ignore them when once established. The man who uses scientific methods in studying all questions is a much safer man to follow than the man who starts out with certain preconceived notions of things. The former throws away all prejudice in his investigations, while the latter is constantly trying to find something to bolster up his preconceived notions. He generally thinks he finds what he is seeking for, but he usually finds them through the refracted vision of mental mirage.

You may say that I have digressed from my subject in this chapter, but you will see if you go back and read the introductory chapter that I did not propose to adopt class-room methods; but said that if in the course of our study of natural laws we found any good illustration that had an application to the philosophy of every-day living, the privilege was reserved of stopping to discuss it.

CHAPTER XXV.

PHOSPHORESCENCE.

Many substances have the power to become self-luminous to a greater or less extent, and for a greater or less length of time, by being exposed to a strong light. This is not usually attended either by combustion or sensible heat, and is called phosphorescence. While it is true of one form of phosphorescence that there is no combustion, it is not true of all. When a diamond is exposed to a strong light and then is taken into the dark it is luminous for some seconds; and certain kinds of calcareous matter have the power to absorb light and remain luminous for some hours.

An apparatus was constructed by Bequerel to examine the phosphorescent qualities of all substances, and he found that most of them possess the quality to a greater or less degree, although in many cases only for a very small part of a second. Clock-faces have been covered with a luminous paint that would absorb enough of light by day to keep them luminous most of the night. If a glass bulb or tube has the air exhausted as far as possible—say

to one-millionth of an atmosphere—the same as a Crookes tube, such as used for getting the X-ray—and then pass intermittent currents of electricity of high tension through it, the glass becomes phosphorescent by the bombardment of the few molecules of air that are left in the tube. This bombardment puts the glass-molecules into such a high rate of vibration as to produce light by a sympathetic vibration of the ether surrounding the molecules. The colors that are made luminous by this molecular bombardment are chiefly those found in the higher part of the spectrum, and are attended with little heat. Other substances emit light after exposure to light for the same reason. The substance is bombarded by light-rays, which cause its molecules to vibrate in sympathy. If we have two tuning-forks tuned to exactly the same pitch and sound one of them, the other will sound in sympathy, although some distance away from the initial sounding-fork. The sound-waves from the first fork bombard the second and make it vibrate in sympathy. So the light-waves set up a sympathetic vibration in the particles of certain substances and they continue to vibrate after the exciting cause is removed, and hence they emit a feeble light.

There is another form of phosphorescence that is due to a very slow combustion or oxidation. If phosphorus is exposed to the air the

oxygen of the air unites with it very slowly and it emits a light without giving off sensible heat. This form of phosphorescence is seen in decaying animal substances, such as fish, and vegetable substances as well. Who has not seen "foxfire" on a damp night in summer in rotten wood? Living animals and insects also possess the power of emitting this peculiar light—the glow-worm and the lightning-bug are instances. With the glow-worm it is only the female that has the power to shine, at least they excel in this quality. The male has his compensation, however, for he has wings. She shines and he soars.

The most striking exhibition of phosphorescence in living things is found in the ocean, especially in the warmer climates. However, there is one exception to the above statement, for there is a large insect in South America called *Fulgora Lanternaria* that surpasses all animals or insects in its power to give out light. This insect is about three and a half inches long, and has a sort of proboscis—rather thick—and about one inch in length, which constitutes his lantern. It is said that the light emitted by these insects is so brilliant that two or three of them will light a medium-sized room.

There are great varieties of living forms, large and small, that emit light, and in some cases very brilliant light, to be found in sea-

water. When the water is agitated, as by the passage of a vessel, its whole path is brilliantly illuminated by millions of little incandescent lamps carried by as many millions of living animalculæ. As we have said, there are great varieties of these self-luminous animals in the various oceans, and they do not all emit the same colors of light. In some of the Chinese seas and in the Indian Ocean these luminous animals impart a fiery-red hue to the water. In other seas the light is white, resembling snow, while in most seas and oceans the light has a warm color something like lamplight, but less intense. Men have been able to read large print by the light of agitated sea-water and to tell the time of night by a watch.

In all probability these living animal forms that are able to emit light have the power to exude a substance similar to phosphorus, which emits light by a slow oxidation when it comes in contact with air or water. There is always sufficient air in water near its surface to furnish the necessary oxygen.

CHAPTER XXVI.

THE EYE.

The eye is an optical instrument of most wonderful construction when perfectly developed. We cannot undertake to describe it fully here, but refer to it because it is the organ in all animals that enables them to sense the outside world through the medium of light. In the lower forms of life the eye is imperfectly developed, consisting of spots, in some cases, of matter sensitive to light-vibration—somewhat, we imagine, on the principle of phosphorescence. Such life does not need the higher forms of optical organs, as it could not appreciate the beauties of nature.

There is a reason why most forms of animal life should be in some degree responsive to the stimulating effect of light, as there are qualities in the higher colors of light that are helpful if not necessary to animal life; qualities that are not found in the dark rays of heat. There is a stimulating effect that one gets from radiant energy, in the form of both heat and light, that cannot be had from other sources. Every sensitive person knows the

difference between the heat of a hot-air register and the radiant heat of an open fire. So that light does not affect animal life simply through the eye. We need to bathe in it as well as see with it.

But to return to the eye. I remember as a schoolboy closing all the shutters of the schoolhouse and holding an atlas for a screen in front of a small hole in one of the shutters, and watching the images of the boys at play outside. They were very small and stood on their heads. I had, in this arrangement, a crude outline of an eye. The atlas was the retina, and the hole in the shutter was the lens that admitted the light. But the eye has many equipments for its protection and easy adjustment to varying conditions that the atlas did not have. It can adjust the refracting power of its lens at will.

The property of the eye that we wish to call especial attention to is the structure of the retina. The retina is the screen lying back of the eye, and is a spreading out of the optic-nerve that runs out from the brain. The retina is to light-vibration what the ear is to sound-vibration. And just as the ear is constructed so as to be responsive to all sorts of sound-vibration, so is the retina of the eye constructed to be responsive to all sorts of color-vibration. It is made up of layers of various structures, and one of them is a layer

of thousands of little rods varying in length, and it is supposed that these rods play a part in re-enforcing color-vibration, something as the cords in the internal ear re-enforce sounds, so that the impression will be more pronounced in the optic and auditory nerves which are the connecting links between physical motion and sensation.

Musical instruments may vary in pitch. The pitch of an instrument is an arbitrary thing, and has been determined by experiment. One may sing a tune in a high or low key, but there is one key that will produce the best effect. For purposes of illustration and to get a better conception of color as a motion, we may consider the eye as responsive to musical tones of exceedingly high pitch; or, that color-sensations are sound-sensations sensed through an organ infinitely more refined and infinitely more responsive than that of the ear.

Whoever has looked through a photographic camera as it is arranged when the photographer is getting the proper range and focus, and before he puts in the slide and tells you to "look pleasant" and "wink occasionally," has seen an image of whatever is in front of it thrown on the ground-glass screen. This is the kind of image that is thrown upon the retina of the eye when we see things. The eye has many advantages over the camera, and

one is that the photograph on the eye carries with it all the colors of the object that is seen in the camera. In the photographic process the colors are carried as far as the sensitive plate, but there they are absorbed, and we have to depend for our picture upon the varying shades between black and white. The high lights as they are reflected from the objects impress themselves more quickly upon the sensitive plate than the shadows of the object, and so we have what is called a negative, which is just the reverse in its shadings from that of the object of which it is a reversed reflection. If, however, we fix these lights and shadows on the plate, which must be transparent, and then lay another sensitized plate upon it and expose it to the light, we shall then get a perfect picture in light and shade of the object photographed. The colors, however, will be absorbed and not appear in the pictures.

We know that the color of any substance is determined by its ability to reflect any particular color and absorb all others. To photograph color, then, it will be necessary to discover some substance that will have its physical structure so changed by the action of the color thrown upon it as to reflect that color from the spot that has been exposed to the colors reflected from the object into the camera and onto the sensitive plate. Many

attempts have been made to photograph color, but as yet without perfect success. The retina of the eye has the qualities necessary to take notice of all the shades of color and all the effects of light and shadow and convey them to the brain, but what takes place there, what is the analysis of the wonderful transition from motion to sensation, is beyond the power of human ken.

CHAPTER XXVII.

SHADOWS.

Wherever there is light there are shadows. The phenomenon of shadow proves that light-rays tend to move in straight lines. Light does move in straight lines, except when refracted, as has been explained in the chapter on Mirage. An opaque body cuts off entirely the light-rays. "If this is true," you ask, "how is it that we can see in shadow?" There are shadows and shadows. If you are in the shadow of the earth at midnight and there is no moon visible and there are heavy clouds, so that the starlight is shut off, and there is no artificial light present, you cannot see. If it were not for the reflection of the atmosphere and starlight there would be total darkness when the sun goes down.

If there were no luminosity in the atmosphere and no reflection from any objects so as to make cross-lights, shadows even in sunlight would be very dark. If the earth and all that is on it, as well as the air and all that is in it, had no light-reflecting qualities and absorbed all the light, we could see nothing in

the brightest sunlight but the sun itself. The light-rays from the sun would enter the eye directly, and not have to be reflected. If we could be fired into space several hundred thousand miles it would be dark all around us, for there would be no atmosphere or any substance to reflect or diffuse light except our own bodies. We could see the sun, moon, earth, and stars. The earth would look like the moon, and would shine by reflected light, just as the moon does. But it would not seem like moonlight, because there would be nothing to reflect or diffuse the light. It is hard to realize what real darkness is—for there is never a night so dark as to be called total darkness.

I once spent twenty minutes alone in what is called the star-chamber of the Mammoth Cave, while the guide left me and went off into a side chamber that led out into the main passage a long way off to show me the effect of light on the ceiling of the chamber at a distance. You can imagine how it seemed down in the bowels of the earth, where there was no living thing, not a worm or an insect of any kind, so that there was absolute darkness and absolute silence. I never realized the meaning of either silence or darkness before.

There is a wonderful exhibition of shadow to be seen under certain conditions of the atmosphere on one of the peaks of the Hartz

Mountains, called the Brocken. If one or more people stand on the summit at sunrise they can see an enlarged shadow of themselves as well as the top of the mountain, together with a house with a tower on it, standing out against the sky in enormous proportions; the clouds and mist form a screen to catch the shadows, and, while it is as easily explained as the shadow of a tree in the summer sunshine, it has an uncanny appearance. It is called the "Specter of the Brocken," and has been looked upon with superstitious awe by the ignorant people for ages past. This specter may be seen both at sunrise and at sunset, but of course on opposite sides of the mountain.

The shadow of the earth upon the moon is very striking when the moon is new.

> "I saw the new moon late yestreen,
> Wi' the auld moon in her arm."

Soon after the sunset of a clear evening when the moon is in its newest phase, it may be seen in the western sky, a bright rim of light encircling nearly half its circumference. The whole body of the moon is seen in a feeble light, just enough to see that it is in deep shadow. This feeble light that we see is a reflection from the earth upon the moon. If there were inhabitants on the moon they would have earthlight, which would be to them what moonlight is to us.

There is another form of shadow that has been brought to our notice by the advent of the X-ray. We have in the phenomenon of the X-ray shadow, a shadow without light—or at least a shadow from nonluminous rays of light, if we may so express it. The so-called photographs by the X-ray are really shadowgraphs. If the hand is held between an X-ray apparatus and a fluorescent screen or phosphorescent screen a shadow of the bones of the hand is seen, and very faintly the flesh of the hand. These rays have the power to penetrate many substances that are opaque to ordinary light and cast a shadow from the more dense parts of the substance or substances through which they pass. The flesh is much more transparent to this ray than the bones, so that if the hand is put over a screen that will become luminous by bombardment—as we have seen in another chapter that some substances will—the X-ray will pass through the flesh but be arrested by the bones, so that the screen becomes luminous around the outlines of the bones and makes what appears to be a shadow. The light does not come through the flesh. Luminous rays do not, but an energy does that creates light when it strikes the screen. Some suppose that there are real particles thrown with great violence through the interatomic spaces of the flesh or other substances through which it passes. This is like the material

theory of light, which most of us think is untenable. Most likely it is ether-waves of great energy and not attended with much heat, and because there is but little heat we can make our experiments very close to the origin of the waves.

It may be that the sun gives off X-rays of great power, if they could be applied nearer than 90,000,000 of miles. They may not have the carrying power to compass great distances that the other waves of radiant energy thrown out by the sun do. The X-ray has the qualities of some of the sun's rays, as in its power to act upon sensitized plates. It is also shown to be able to burn tissue if that be exposed to it for a sufficient length of time. If a long enough exposure were made, it would destroy live tissue as surely as heat does.

CHAPTER XXVIII.

EXPLOSIVES: GUNPOWDER.

Among the forms of energy that the modern world is familiar with are Explosives, which do a vast amount of work—some beneficent, and some purely destructive. The first and most familiar is gunpowder. In these days of wars and rumors of wars, when such quantities of powder are made and burned, it may be a matter of interest to know how this is made and what is its action.

Gunpowder is very old, so old that it is not known accurately who first invented it. The invention is claimed by the English for Roger Bacon (1214-94), and by the Germans for Berthold Schwarz (about 1320). It is most likely, however, from references that are found in older manuscripts, that neither of these gentlemen is entitled to the honor. It seems also to have been known in China from even earlier times. It is claimed that its first use in war was by the Europeans in the Moorish wars in the fourteenth century, perhaps introduced by the Moors. There is a historical reference to the effect that at the battle of

Crécy, or Cressy, in France, between the French and English (1346), "villainous saltpeter" was used.

Ordinary gunpowder is made of three ingredients, to wit: niter, charcoal, and sulphur. Seventy-five per cent. of the mixture is niter, 15 per cent. charcoal, and 10 per cent. sulphur. These ingredients are thoroughly ground and as thoroughly mixed together. The whole is then dampened to a certain extent with water and pressed into cakes by hydraulic pressure.

It is said by experts that very little if any change has been made in the composition of gunpowder since it was first introduced. Very much, however, has been discovered regarding its economical use for various purposes. If we use powder for firing a charge of birdshot from a smooth-bore shotgun we shall use a very different grain of powder from that we would use in firing a cannon-ball or even an ordinary rifle.

If we examine various grades of gunpowder we shall find that the difference is simply in the size of the grains; the finer the grain the more quickly it will burn when ignited. If we should attempt to fire a heavy cannon-ball with the kind of powder that we would use in a bird-gun, in all probability the cannon would burst.

Before attempting to give the reason for

this let us further analyze the chemical composition of gunpowder. It will be observed that powder before it is burned is simply a mixture; when it is burned the carbon unites with the oxygen of the niter, creating carbon dioxide as well as setting free a large amount of nitrogen gas. One cubic inch of gunpowder will produce 207 cubic inches of gas at ordinary atmospheric pressure and when the temperature is only 60 degrees Fahrenheit. Of course when the gunpowder is burned in a confined space the gases are intensely heated and will therefore occupy a much larger space than at a lower temperature. By keeping the fact in mind that powder, in its gaseous state, occupies so much more room than it does in the solid state, the reader can readily understand where the gunpowder gets its energy when it is burned. Its gases must expand instantly and enormously. Gunpowder does not require air to explode it, because the niter that is in the mixture is very rich in oxygen, so that when it is heated to the point of ignition there is an instantaneous union between the carbon of the charcoal and the oxygen of the niter, producing a gas. It has required a vast amount of experimentation to find out how to use powder safely and economically in the various kinds of guns where it is used as an explosive.

We have already said that gunpowder was

first pressed into a solid cake, after the ingredients had been sufficiently refined and mixed. This cake is now broken into grains of various sizes, according to the use to which the powder is to be put. If we wish to fire a charge of small shot, quick action is desirable, and therefore we use fine-grained powder, because the finer the grain the more quickly it is converted into gas when ignited. The small shot are so light that they possess but little inertia to be overcome.

We have a very different problem, however, when we wish to fire a shot weighing several hundred pounds from a cannon. The inertia of a heavy shot is so great that it requires a little time to put it in motion, however great the force may be that tends to expel it. If we used the same kind of powder that we did in our shotgun the cannon would burst before the ball could be set in motion, because of the exceedingly quick action of the fine-grain powder. The coarser the grains are, the slower the powder will burn. The heavier the projectile to be fired the coarser the grains of powder must be in order to fire it with safety and economy. With heavy projectiles it is necessary that the powder burn slowly, in which case the projectile begins to move before the powder has nearly all burned, so that it continues to burn until the projectile is expelled from the mouth of the cannon. It will

be seen that there must be a fixed relation between the weight of the projectile and the size of the grains of powder used to drive it. The powder should be of such quantity and size, as to its grains, as that the time required to consume it shall correspond to the time that it requires for the projectile to reach the mouth of the cannon. If the powder is too coarse it will not all have burned before the shot is expelled, in which case a part of the powder will be blown out with the ball. On the other hand, if the powder is too fine-grained it will put too heavy a strain upon the body of the cannon and there will be danger of a premature explosion, because the gases have formed too rapidly. The grains of powder used in some of the largest guns have grown to monstrous sizes; some of them measuring two inches on a side. It is a misnomer in this case to call it powder. It took its name from the fine powder that was first used, which, as every one knows, has a very small grain. It is estimated that powder, when it is first ignited, owing to the intensely heated condition of the gases evolved, expands momentarily more than 2,000 times—which is equivalent to a pressure of fifteen and one-half tons to the square inch. At a temperature of 60 degrees Fahrenheit it only expands about 207 times. When we estimate the number of square inches contained in the area of the bore of some of our large

cannons, and multiply that sum by fifteen and one-half, we get something of an idea of the energy that is behind a cannon-ball when it is fired. No wonder that it moves with great velocity and that it hits hard when it strikes!

CHAPTER XXIX.

EXPLOSIVES: POWDER AND NITROGLYCERIN.

We have seen in the chapter on gunpowder that when a grain is burned the gases which are the product, at a temperature of 60 degrees F., occupy over 200 times the space of the original grain of powder. To make a more concise statement, a cubic inch of gunpowder will occupy over 200 cubic inches when resolved into the gaseous state, at a temperature of 60 degrees F. As a matter of fact, at the moment it is burned it occupies a very much larger space momentarily owing to the violent expansion produced by the intense heat generated.

Let us stop a moment and inquire what is involved, or rather what takes place, when we liberate the imprisoned gases that have been held in a solid form by the attraction of chemical affinity.

There are two forces that are continuously active, one which tends to hold the atoms together in a molecule, which we call chemical affinity, and another which we may call a repulsive force, which tends to drive these atoms

away from each other when they are released from their mutual attractions. The attraction that the atoms have for each other acts powerfully through a very short space, while the opposite is true of the repulsive force. When the atoms are forced apart to a certain distance this attraction is overcome by the tendency of the atoms to fly apart and assume the gaseous state in which the same number of atoms occupy a much larger space. Suppose we put a small amount of gunpowder into a vacuum of sufficient size to hold all the gas that the powder will produce when burned at ordinary atmospheric pressure. Now, if we explode it under these conditions it burns quietly and there is no explosion, because the gas has room to expand without resistance from the surrounding air. If, however, we confine the powder in the shell of a cartridge and explode it, we hear a report. The report is caused by the gaseous particles striking with great violence against the surrounding shell when they are suddenly released. Millions of little projectiles are fired against the walls of the shell, producing the effect of a severe blow of one hard substance against another. When powder is burned inside of a cannon these atomic projectiles are released and they strike the larger projectile in such numbers and with such force that the ball is driven from the gun with a velocity that indicates that there was

an enormous quantity of stored energy in the powder. If we could measure the energy expended on the ball and against the walls of the gun when it is fired it would be found to be an exact measure of the energy required to combine these released atoms into the solid state they were in before the explosion took place.

As compared with many other explosives, gunpowder is exceedingly slow in its action, and it is this quality that gives it its great value as an agent for firing projectiles. There are many other explosives that act with greater promptness and with greater energy than gunpowder. And it is because of this prompter action that these high explosives are valueless for throwing projectiles. This leads us to a discussion of the properties of nitroglycerin.

Nitroglycerin is made by subjecting ordinary glycerin, which is a transparent fluid, to the action of a mixture of nitric and sulphuric acids. The molecule of nitroglycerin is a very complicated one; it contains three atoms of carbon, five of hydrogen, three of nitrogen, and nine of oxygen. It contains within its own structure the elements for producing water, carbon dioxide, and nitrogen. And when it is exploded it takes the following form: One molecule of nitroglycerin produces three molecules of water, three molecules of carbon dioxide and two of nitrogen gas. It

will be seen that there are not enough atoms to form even molecules when broken up by explosion, but these fractions unite with the fractions of the other nitroglycerin molecules that are exploded at the same time. The nitroglycerin molecule is held together by a force that is only a little greater than the forces that are tending to rend it asunder. The student in chemistry has learned that the highly organized substances (and by this we mean substances that contain a large number of atoms in a single molecule), are much less stable than the simple compounds are, so that they are much more easily broken up by some extraneous force.

Very curiously, nitroglycerin is not sensitive to heat like ordinary gunpowder. The writer has seen a piece of the gelatin form of nitroglycerin fired with a match, and it burned rapidly, but not explosively, until it was entirely consumed. There was enough energy set free to have annihilated a regiment, if it had been done as suddenly as it is when nitroglycerin explodes. It does not burn rapidly like gunpowder, so that the gases are set free very slowly under combustion; but if it is subjected to a sudden jar that is sufficiently powerful, the atoms are suddenly released from the unstable power that holds them in the nitroglycerin molecule, and they all together take on the new arrangement of atoms

heretofore mentioned. In doing this an enormous amount of energy is suddenly released and millions upon millions of atomic projectiles are fired in every direction with such force and such velocity that whatever stands in its way is rent asunder. If we should take a pound of loose powder and lay it upon the top of a large rock and explode it, there would be a great flash extending high into the air, but not a loud report. On the other hand, if we should place a pound of nitroglycerin in the same position unconfined and explode it by means of concussion, there would not only be a stunning report, but the rock would be rent into a thousand pieces. If the quantitative relation between the gunpowder and the nitroglycerin is so adjusted that each quantity has the same amount of stored energy that is freed, in the one case when it is burned and in the other when it is exploded by concussion, there will still be this great difference in the phenomena when each is exploded in the open air. What this difference is we will attempt to explain in the succeeding chapter.

CHAPTER XXX.

HIGH EXPLOSIVES.

In our last chapter we saw the difference between the explosion of gunpowder and nitroglycerin under the same circumstances in the open air. We saw that the gunpowder exploded with a great flash, but not much of a report, while the nitroglycerin exploded with a terrific report, and at the same time rended the great rock into a thousand pieces. Why this difference? It consists (other things being equal) in the difference in suddenness with which the energy has been liberated in the two cases. In order to get a conception of what is meant, let us try an experiment.

Suppose we take a board that is three feet square and move it in the air in the direction of its face or broadside. As long as we move it slowly it will require but little force, but the faster it is moved the greater will be the resistance offered by the air, until we can conceive of a velocity so great that it would be equal to striking a solid substance like a sledge on an anvil. And this is what takes place

when nitroglycerin is exploded in the open air. Owing to the immense velocity of the atomic projectiles, they have to lift the air above *all at one instant*. It is as though the air for the moment were a solid substance, extending upward to a great distance, and each square inch weighed 15 pounds. The pressure of the air when our board is standing still is equal on both sides, and when it is moved slowly the air molecules have time to fill in behind it so that the pressure is scarcely perceptible with a slow movement. If the velocity, however, is very great there will be a vacuum formed behind the moving board, and the resistance would soon break it into splinters. If we should rest this board upon its four corners horizontally and could by some means remove the air beneath it and create a vacuum the pressure on the upper side would be equal to nine tons weight. So, too, a rapid movement through the air would create a vacuum behind the board so that the air-resistance comes upon one side. And if the velocity should be increased to 1,200 miles per minute, say, the air would present an almost impenetrable barrier. In the case of the nitroglycerin explosion, it is this intense rapidity of expansion which condenses or packs the air above it, making it impenetrable to the sudden expansion, when the force reacts or "kicks" back at the rock on which it was placed, and rends and heats it.

The resistance is so great in the direction of the air that it is easier for the explosion to work downward through the rock than upward through the air. The air in this case serves the purpose that a cannon-ball does when forced in on top of a charge of powder. The air offers greater resistance to the explosive energy of nitroglycerin than the cannon-ball does to powder, so that if a charge of nitroglycerin were exploded inside of the barrel of a cannon it would burst the cannon in pieces rather than find vent through the opening, which has no other charge in it than that of the air. It will be seen from the preceding that the air offers a greater resistance to exceedingly high velocities than a solid wall would do. If we place a quantity of nitroglycerin upon the ground and explode it, its greatest effect will be exerted downward, and it will tear a large and deep hole in the surface of the earth.

Here is a curious fact in nature; the substance which is seemingly the most yielding to slow movements offers a resistance greater than that of a solid rock to velocities that are sufficiently high. The foregoing will more fully explain why gunpowder remains the most valuable agent known for firing projectiles, while it is far exceeded by nitroglycerin and other high explosives in its destructive effects when used for rending rocks or destroying

earthworks, vessels, or buildings. It is the difference between slow and quick expansion.

Nitroglycerin has been largely supplanted for military purposes by a substance called gun-cotton. Gun-cotton is formed by the same process as nitroglycerin. Ordinary cotton fiber is subjected to the action of nitric and sulphuric acid combined. After it has been subjected to this process and dried and finely pulverized it ignites at a low heat and explodes like gunpowder, with the difference that there is no smoke accompanying the explosion of gun-cotton. Smokeless powder is coming into favor for military purposes because the enemy cannot see from whence the firing comes. On the other hand, it has the disadvantage that the enemy is not so easily discovered as when the old form of powder is used. The gun-cotton molecule, like nitroglycerin, is a complicated one, consisting of a number of atoms each of carbon, hydrogen, nitrogen, and oxygen, and is so loosely held chemically that, like nitroglycerin, it can be exploded by concussion. For a number of years after the discovery of gun-cotton it was not known that it could be exploded in this manner. This latter discovery has brought it into great favor as an explosive for torpedo and mining work in military operations. It will explode with as great force when floating in water as when perfectly dry. The fact that

it can be stored saturated with water precludes the possibility of danger from fire, as there was with the first preparations of gun-cotton. Like nitroglycerin, it is not necessary to confine it in order to render it explosive. Four hundred and fifty pounds tied up like a bale of cotton and sunk in the water to some distance and exploded will throw a cone of water with a base not less than 225 to 250 feet in diameter sixty feet into the air. This would be sufficient to destroy the largest battleship.

The method of exploding gun-cotton used for submarine torpedo work is by electricity. The cotton is exploded by what is called a detonator, which is placed within the bulk of the wet gun-cotton. This detonator is made of some kind of fulminating powder that may be fired by a spark of electricity. The fulminate is placed inside of a small block of dry gun-cotton and the whole is sealed up so that it is waterproof. The object of using the dry gun-cotton is to get a sufficient amount of concussion to explode the wet gun-cotton. Dry gun-cotton is very readily exploded by a very small portion of fulminate, which is not sufficient to explode the cotton when it is wet. Electricity fires the fulminate, the fulminate the dry gun-cotton, and this in turn the wet. Gun-cotton may also be fired from a cannon set in a shell containing water; the shell is

exploded when it strikes by the action of some form of detonator. Gun-cotton is safe to handle if kept wet and kept away from explosives. In fact, you could smother a fire out with wet gun-cotton the same as with a wet blanket, and after it had performed this service it could be utilized for blowing up a man-of-war without drying it out.

A great number of explosives have been invented from time to time, under various names, such as gun-cotton, nitroglycerin, dynamite, litho-fracteur, cotton-powder, tonite, glonoine, dualine, saxifragine, mataziette, glyoxiline, blasting-gelatin, and many other unpronounceable names. All of these, like gun-cotton and nitroglycerin, are nitro-compounds and are substantially the same. Like many other new things the name is the newest feature. Dynamite is simply nitroglycerin mixed with some substance that gives it rigidity and at the same time makes it easy to handle. In this form it is used very extensively for blasting purposes and is sometimes called giant-powder. It is very convenient for this purpose, because it is only necessary to drill a hole in a rock and insert a stick of dynamite which is pressed into the proper length and diameter. No tamping is needed.

The base of all these explosives is either gun-cotton or nitroglycerin. Gun-cotton is a nitro-compound in a solid form, while nitro-

glycerin is also a nitro-compound, but in a fluid state. The discovery of gun-cotton and nitroglycerin has introduced many new features into the methods of modern warfare. For instance, a new department of the cavalry service has been organized in some countries called the cavalry pioneer. Men are selected because of their daring and are furnished with fleet horses and light armor, as well as a belt filled with gun-cotton or nitroglycerin charges, detonators, and time-fuses. It is the business of these cavalrymen to make a dash into the enemy's territory and destroy bridges, disable railroad tracks and tear down telegraph lines. Two of these cavalrymen equipped with fleet horses can make a dash close to the enemy's lines, plant torpedoes on a line of railway, fire a slow match and be out of harm's way inside of a minute, and the explosion will tear up the track for several feet. Or they may attach one of these little destroyers on the side of a telegraph-pole and by the same method in the twinkling of an eye bring it to the ground, when in another minute's time they can sever the wires with cutting-pliers carried for that purpose. Or they may plant two or three or more torpedoes upon a railroad bridge, apply a slow match, and before they have proceeded a hundred yards the bridge is a wreck. In old times, when a battery of guns was abandoned to the enemy, it

was the habit to spike them by driving a piece of metal into the fuse-hole. It was often the case, however, that these spikes could be taken out by the enemy and the cannons utilized. By the use of these modern explosives, however, a gun can be rendered entirely useless by putting a small charge of dynamite or gun-cotton in its mouth and exploding it.

There was a form of explosive that promised at one time to be very valuable that was discovered by C. H. Rudd, an electrician in the employ of the Western Electric Company of Chicago. Very little is known of this explosive because the inventor was killed while experimenting, so that the secret, so far as the details are concerned, died with him. In general, it may be described as follows: It is well known to all chemists that the compound called chlorate of potash, or potassium chlorate, is very rich in oxygen. When it is heated to a certain degree the oxygen passes off very rapidly, but so gradually as not to amount to an explosion. Mr. Rudd's discovery was that when the chlorate was heated up nearly to the point where the oxygen began to pass off, all of the oxygen could be thrown off from the chlorate at the same instant by concussion—in the same manner that nitroglycerin and gun-cotton are exploded. In order to bring this explosive into practical use it was necessary to devise some means by which the potassium chlorate

would be brought to the proper temperature for explosion by concussion, in all places where it might be useful. Mr. Rudd was working out these details when the accident occurred that cost him his life. In general, he proposed to use the electric current for raising the temperature of the chlorate to the proper point for explosion by concussion.

It was claimed for this explosive that it was as safe to handle as any other commodity and that its explosive powers were as great or greater than nitroglycerin. Mr. Rudd's discovery offers a fruitful field for further investigation, which would prove exceedingly interesting and perhaps valuable. The use of explosives as applied in modern warfare has become a science of its own, the study of which is exceedingly interesting.

CHAPTER XXXI.

FIRING A SHOT.

In a previous chapter it was explained in a general way that there should be a fixed relation between the size of the grains of powder used in a cannon and the ball that is fired. In order to determine accurately what this relation shall be, it is necessary to know just what the powder and ball are doing between the time the powder is ignited and the time that the ball leaves the muzzle of the gun. Roughly speaking, the ball will be one-hundredth of a second in traveling from one end of the barrel to the other. From the fact that the ball is slow in starting, one would infer that it would move from the starting-point to the point where it leaves the muzzle with a uniformly accelerating velocity. This we find to be the case if we use the right amount of powder, with grains the right size. The greatest velocity that the ball acquires is at or near the moment it leaves the muzzle of the gun. This is called its initial (beginning) velocity.

If the gunner knows the initial velocity of the projectile as well as its weight he can readily calculate how far it will fly and how hard it will hit an object at any given distance within its range. Several kinds of devices have been invented to determine the speed of the ball not only at all positions inside of the gun, but outside as well. It is claimed for some of these that they will measure accurately the speed of a cannon-ball to the millionth part of a second. And there is no doubt but with the aid of electricity such a degree of accuracy is easily possible. For measuring the speed of a ball inside of a gun, telegraph stations, so to speak, are established at a number of points inside the barrel at equal distances apart. These points, or stations, are each connected by a wire with an observing-room, where the records are made. The ball in its passage out of the gun makes or breaks the electrical connection at each station, according to the apparatus used.

In one form of apparatus, called the chronoscope, an electric spark is caused to pass from the end of the wire to the periphery of a wheel that is revolving at a fixed rate of speed. The face of this wheel is covered with a coating of lampblack. When the spark passes it will burn the lampblack, leaving a small spot on the face of the wheel.

Suppose the cannon is ten feet long and that

there are ten stations equidistant apart inside of the barrel. When the ball is fired it sends a spark to the revolving wheel, which leaves a record in the form of a spot, as it passes each station inside of the barrel. If we now stop the wheel and examine the record it will be found that the space between the first and second station is longer than any of the rest, and that each succeeding space grows shorter until the whole length of the gun is covered. This record shows that the ball moves slowly in the start, but moves faster and faster until it leaves the muzzle. By this same apparatus the speed of the projectile may be determined at any point after it leaves the mouth of the gun.

The applications of modern science coupled with modern invention are enabling the operations of war to become more and more an exact science. One shot from a cannon accurately aimed, with a full knowledge beforehand of what it is able to do when it reaches the target, is worth a thousand fired at random. This is especially true in naval warfare. Here more perhaps than in any other place the battle is one of skill rather than numbers.

Owing to the development of these instruments of precision, by which the relation of each factor to that of every other in the firing of a shot is readily determined, a great ad-

vance has been made in the construction of modern guns for coast defense and long-range firing. There are great steel rifles now in place on our coasts, with a bore of twelve inches, that will fire a shot twelve miles, and no steel armor used for ship-protection could withstand such a shot. These guns are mounted on disappearing-carriages. They are loaded and aimed behind the earthworks and then elevated and fired, after which they immediately disappear to a place of safety. The gunners are not exposed to the direct fire of the enemy, and the gun itself only for a short time. We are told that the United States has now under construction a still larger gun that will shoot still farther, and one shot well aimed will be sufficient to disable the strongest battleship that floats. This gun will weigh 140 tons when completed, and will have a bore of sixteen inches in diameter. Each shot will cost the government $1,000, but it will be much more economical to fire $1,000 shots than $500 shots if the former sinks a $2,000,000 ship each time it strikes the target—while the latter only makes an indentation in the armor, without piercing it. The present 12-inch bore guns require 520 pounds of powder to fire them.

Any new invention that increases the destructiveness of the implements of warfare is a step toward the good time coming when

there will be universal "peace on earth" if not "good-will toward men." If the first is enforced, the latter may come in the course of time, when men see the futility of fighting.

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